COMPILATION OF WORKSHOP MATERIALS:
Workshop for An Assessment of the Present and Potential Role of Weather Modification in Agricultural Production

Compiled by
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Fort Collins, Colorado

This workshop was held at CSU, July 15-18, 1975.
Sponsored by RANN and NSF.
Principal investigators: Sylvan Wittwer and Lewis O. Grant
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Department of Atmospheric Science

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held at

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Moisture stress occurring during this period can result in large yield decreases. It should be recognized that this stress is the result of the combination of several meteorological factors which affect the demand for water and the supply available. Experiments have shown that a severe day of stress in the period slightly before tasseling will result in a 1-2% yield loss per day. During the tasseling-silking period this loss can go up to 7%, and under extreme conditions a relatively short period can result in a complete crop failure. During the grain filling period, a day of stress reduces yield 3-4%.

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AN ASSESSMENT OF THE PRESENT AND POTENTIAL ROLE OF WEATHER MODIFICATION IN AGRICULTURAL PRODUCTION

I. ASSESSMENT GOALS AND PLANS

The broad objective of the assessment of the present and future role of weather modification in agricultural production is to make an authoritative evaluation of the present and potential role that weather modification can take in increasing national and world agricultural production. A specific objective includes the preparation of an authoritative document that can receive wide distribution and provide for extensive utilization of the results of the assessment. This document will:

1. Identify the geographical areas and types of weather modification research that can have the greatest impact on agricultural production and other renewable resources.

2. Provide background and guidance to NSF and other federal and state research managers on areas and types of weather modification research that can have the greatest impact on agricultural production and other renewable resources. This can apply to those with responsibilities in the discipline areas of weather modification, meteorology, agriculture and atmospheric science.

3. Provide information to state and federal public administrators (Office of Technical Assessment, OMB, etc.), legislators, courts and the general public that can assist them in making wise decisions and plans regarding applications of weather modification.

4. Delineate the needs, required efforts, and methods for a longer term, continuing evaluation of the interrelations between weather modification and agriculture.

The scope of the assessment will incorporate weather modification in a broad context which will include all identifiable modifications of the atmospheric environment. It will deal extensively with, but not concentrate on, precipitation control. An additional specific objective will be to initiate dissemination of the findings to technical and governmental groups, research managers and administrators, commercial users, and to the general public.

The actual assessment is being carried out in several stages. The principal investigators, with the aid of advisors and consultants, have organized and conducted the workshop to identify the needs of agriculture and the capabilities and risks of weather modification. This report is a compilation of the workshop materials. Many weather modification effects are being considered: changes in precipitation, hail suppression, storm abatement, wind reduction, temperature modification, cirrus cloud production, fog production, change in surface albedo, orchard heating, lightning suppression, etc.

Areas where weather changes would be beneficial to agriculture have also been identified: additional rainfall, reduced rainfall, a change in rainfall frequency, less hail, less wind, longer growing season, lower maximum temperatures, higher or lower minimum temperatures, earlier (later) spring soil heating, etc. Consideration has included the broad spectrum of agricultural and other renewable resource production and problems: crops, range and livestock, forestry, disease, weed and insect control, soils, plant nutrients, and environmental stresses.

Interpretations and judgements are being made in an attempt to describe the portion of weather modification research that offers the most practical and economic solutions to agricultural problems.

All materials developed from the workshop are being organized, condensed and/or expanded. These materials are being reworked into three types of documents:

1. Those documents which directly incorporate the materials from the workshop.

2. An <u>Executive summary</u> which emphasizes conclusions, recommendations, rationale, and implementation procedures and will be addressed primarily to users, administrators, policy makers, etc.

3. A <u>technical version</u> primarily for the scientific community.

II. ASSESSMENT CONCEPTS

A. Formation for Assessment Document

Recommendations

Rationale

Implementation

B. Background on Food Production

1) Agricultural production has expanded at least as rapidly as population during the past 25 years. Little significant change has occurred in nutritional levels in the developing countries, fig. I.

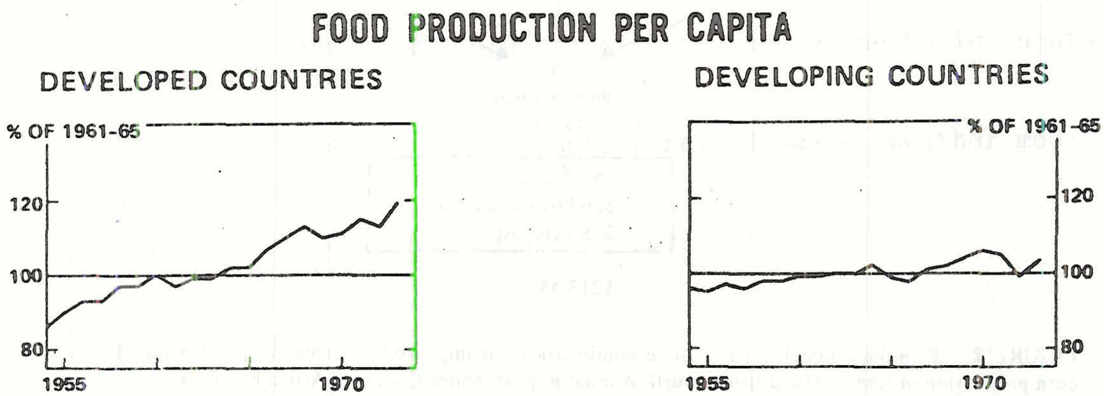

Figure I

2) Agricultural production can maintain expansion, primarily through increase in yield but also through expanded area, during the next 25 years. The increase in yields can come primarily from expanded use of present technology and also from expansion of technology. It may be more difficult to maintain nutrition at even its present unsatisfactory levels in the developing countries. The benefits that can be derived from both high and low cost management practice and the combination of these is shown in Figure 2.

(8) Use of Improved Agronomic Practices as Alternatives to Weather Modification (or to Complement it)

(9) National Program for Evaluating and Monitoring Weather Modification Operations

(10) Better Long-Range Forecasting to Permit Optimum Application of Weather Modification Techniques to Agriculture

Two other specific recommendations were considered by portions of the panel, but time did not permit their consideration by the whole group.

(1a) Snowpack augmentation for supplementing water supplies to stabilize agricultural production.

(2a) Increase capacity to protect against radiation frost.

C. Rationale for Panel Recommendations

(1) Enhancement of Precipitation from Early July through August in the Corn Belt.

R. Shaw

This period appears to have the greatest requirement for rainfall augmentation for two reasons:

1. This period is characterized by a normal water demand greater than normal rainfall provides, and

2. moisture stress during this period causes significant reductions in corn yield.

During this period, a deficiency of rainfall of several inches occurs with normal weather. Over a major portion of the corn belt water use is near 10-11 inches. Normal rainfall is less than 8. During periods of below normal rainfall, any soil moisture reserve present is rapidly depleted, and, to avoid stress under high demand days, which occur frequently during this period, the moisture in the soil profile must be at a high level. In many years, rainfall augmentation would be beneficial.

Moisture stress occurring during this period can result in large yield decreases. It should be recognized that this stress is the result of the combination of several meteorological factors which affect the demand for water and the supply available. Experiments have shown that a severe day of stress in the period slightly before tasseling will result in a 1-2% yield loss per day. During the tasseling-silking period this loss can go up to 7%, and under extreme conditions a relatively short period can result in a complete crop failure. During the grain filling period, a day of stress reduces yield 3-4%.

(1.1)

J. G. Ross

One of the recommendations for agricultural use is rain increase during July and August in the corn belt. In this area, over 60% of the rain during this period occurs from nocturnal clouds. Nothing is known of their dynamics or methods of seeding. High priority should be given to obtaining this knowledge as quickly as possible.

Money for research on this problem should be made available through the USDA and preferably through the experiment station system.

(2) <u>Reduction of precipitation and decreased cloud cover through September and early October in the Corn Belt.</u>

C. Tanner and D. Baker

The ripening and curing of corn and soybeans frequently are delayed in the eastern corn belt because of unwanted precipitation, lower evapotranspiration, and decreasing sunshine. In addition, untimely rains reduce field trafficability and delay harvest. These delays in ripening and harvesting result in grain losses of up to two bushels per acre of soybeans and five bushels per acre of corn. Much greater losses can occur in a few extreme years. Very importantly, valuable fuel is required to dry these high-moisture grains. Additionally, soils are damaged by harvester traffic if the soils are too wet, and the wet soils also mean more power is required.

Decreasing precipitation and cloud cover frequencies in the eastern corn belt would increase the probability of timely harvest without yield and quality loss and without artificial drying. In the western corn belt suppression of precipitation and cloud cover usually would not be desirable and in some years precipitation augmentation would be helpful.

(3) <u>Enhancement of precipitation except during harvest periods for Winter and Hard Red Spring Wheats.</u>

J. Ramirez

The wheat crop in the Great Plains will generally benefit from additional rainfall amounts throughout its growing season except during the harvest period. The wheat plant needs the moisture to the seeding depth for germination while optimum returns from additional moisture may be altered if made available especially in the heading, bloom, and milk stages of the crop development. Independent estimates suggest that this benefit can be as much as 2 to 3 bushels/acre/inch of additional moisture.

(5) Possible benefits of weather modification on range land production.

C. W. Cook

The range area is herein identified as the 17 western states west of the 100th meridian. Approximately 50% of the land area of this area is range land that has no alternate means of producing food other than through grazing animals. Range types are perhaps classified as range because of low rainfall, rough topography or timber overstory.

All range lands undergo a natural seasonal period of low soil moisture stress when plants are forced into dormancy. Drought can be of two types throughout the range area which consists of (1) below normal precipitation for a number of years or (2) below normal precipitation during the normal dry periods within a year. These cause wide variability on range forage yield among years which require great flexibility in livestock production. This is the most complicated problem facing the livestock enterprise of the western range area.

Complementary Moisture. Moisture during mid-growing season will increase plant biomass, whereas supplementary moisture during the normal dry season will increase not only plant biomass but also nutrient value of forage to meet physiological requirements of animals that would otherwise be deficient.

It is true that most range lands would benefit from increased precipitation especially where normal annual precipitation is 18 inches or less. Higher elevation ranges including the montane, a subalpine and alpine areas may not produce additional range forage from increased precipitation over and above the normal now received, but plant growth would not be hampered and water yield would be enhanced.

Increased General Precipitation. If general annual precipitation were increased by one inch in areas normally receiving 7 to 18 inches, it has been found that there is a direct ratio of herbage yield with each increment of supplementary water. For instance, this varies from about 100 to 160 pounds of forage per inch of annual precipitation on desert and mid grass areas respectively.

Increased Precipitation on Call. On the shortgrass plains and the intermountain Great Basin area, the critical period when an additional inch of rain would be most beneficial would be during July and August and in the Southwest. This additional one inch would be most beneficial during June and July. In the short grass ranges of the Great Plains area it was found that when rains were low in August or July, steers gained only 0.3 pounds per day and required 3.5 acres per month compared to years when one inch more precipitation was received in either July or August. Steers gained 1.75 pounds per day and required only 3 acres per month. This was an increase of 14.78 pounds per acre more beef as a result of the one inch of precipitation. In case of a cow-calf operation, about 10 pounds more gain per acre was obtained as a result of an additional inch of precipitation during these critical months. Torrential showers on desert areas during the summer months of June to

September do not contribute substantially to increased herbage yield but rather run off and cause flood waters.

Other Environmental Factors. Hot dry winds during the spring and summer are a deterent to forage yield because of transpiration stress on plants which results in decreased herbage growth.

A cold backward spring at high elevations can reduce total annual herbage yield by as much as 50 percent of normal. This can be cool days and cooler nights or light frosts after plant growth has made substantial herbage yields.

Research Needs. The development of simulation models that includes moisture and temperature along with other driving forces and interactions with state variables such as soil type, topographic features, grazing systems, etc., are needed for an understanding of biological systems and their reactions to management and weather modification.

(6) Develop information and education programs on weather and weather modification, particularly as they affect agriculture and other renewable natural resources.

Henry Lansford

To permit weather modification technology of proven feasiblity to make an optimum contribution to solving weather-related agricultural problems, it is necessary to systematically disseminate complete and accurate information about what is and is not known about weather modification, including its limitations as well as its capabilities. Such information will be extremely valuable to farmers and other potential beneficiaries of weather modification technology in making intelligent decisions about when, how, and if it should be used. It is also important for such information to be communicated to groups such as those who may be subject to economic impacts, both favorable and unfavorable, from agricultural applications of weather modification: those who may be involved in writing and passing legislation to regulate weather modification activities; those who may oppose weather modification because of real or imagined environmental impacts; and the general public, which ultimately has the power to decide whether or not particular weather modification projects will be allowed to proceed.

The agricultural extension service appears to be the most effective vehicle for implementing a program of weather modification information and education for potential users in the field of agriculture. Although the requirements of such a program would vary widely from region to region and state to state, it would be useful for some basic resource materials to be developed at the national level, with the understanding that they may be used in different ways to meet varying local needs.

The question of where a program might be centered for disseminating accurate and objective information on weather modification to other audiences is more difficult to answer. This program should not be a public relations effort for indiscriminate promotion of weather modification, and every effort should be made to prevent its being viewed as such by the public.

It would be useful for this problem to be considered by a working group that includes people knowledgeable in fields such as agriculture, weather modification, environmental quality, politics, sociology, and public information. They could consider, first, whether such a program is feasible and desirable and, second what role organizations such as NSF, USDA, the MAS, and others might play in it.

This effort, along with the development of the educational materials on weather modification for use in a program based in the Agricultural Extension Service, might be supported jointly by NSF's weather modification and public understanding of science programs.

References:

Lansford, Henry. Weather Modification in the High Plains Region: Some Public Policy Issues, paper presented at the Annual Symposium on Desert and Arid Zones Research of the Southwestern and Rocky Mountain Division of the AAS, Ft. Collins, Colorado, April 27-28, 1972

Lansford, Henry. Weather Modification: The Public Will Decide. Bulletin of the AMS. 54:7, July 1973

(7) An operational capability should be developed and tested to reduce lightning fire ignitions and fire danger in high value commercial forests, watersheds and forest recreation areas.

J. Barrows

Background. Extensive research by the USDA Forest Service has established the scientific and technical basis for reduction of lightning fire ignition through application of special cloud seeding methods. During the period from 1953 through 1975 Project Skyfire at the Northern Forest Fire Laboratory has produced the following results:

1. Determined the basic characteristics of mountain thunderstorms.

2. Identified the type of lightning discharge most likely to ignite forest fires. This discharge (known as an LCC flash) is characterized by a long continuing current phase.

3. Developed both ground based and airborne systems for the remote sensing and measurement of lightning discharges.

4. Developed high output airborne silver iodide generators and the technology for their use in massive seeding of growing cumulus clouds.

5. Determined through randomized field experiements that cloud-to-ground lightning can be reduced and lightning characteristics altered by massive seeding of connective cumulus cloud systems. The results show a 70 percent reduction of cloud-to-ground lightning and a 25 percent reduction of continuing current intervals for hybrid LCC flashes.

6. Performed intensive statistical analyses and review of lightning modification results. The experimental results show a very high level of statistical significance. It is estimated that the reported lightning modification could reduce fire ignitions in forest fuels about 90 percent.

Impact. In the United States 10,000 to 15,000 lightning-caused forest fires occur annually. These fires impact a variety of forest resources and often provide a threat to public safety, communities and resource based industries. In particular lightning fires damage urgently needed commercial timber resources. They also impact watersheds serving agricultural lands and both urban and rural communities.

Studies performed in 1972 estimated that short term results (4 to 6 years) of a weather modification pilot program in carefully selected areas in 8 western states could:

1. Reduce area burned by 30 percent saving 328,000 acres.

2. Reduce commercial timber losses by 40 percent saving 497 million board feet.

3. Reduce other resource losses by 30 percent providing a saving of $39 million.

4. Reduce lightning fire control costs by 25 percent providing a saving of $25 million.

Implementation. In view of the progress made in lightning modification research, the impact of lightning fires on forest resources, and the opportunity to reduce losses, it is of critical importance to continue and to strengthen a weather modification program directed at lightning-caused fires in high value forests. The task force recommends that the USDA Forest Service in cooperation wtih other interested agencies and local groups develop pilot projects involving both research and fire control units. It is suggested that these pilot lightning fire suppression projects include carefully selected areas in the following western regions:

1. Western Montana and Northern Idaho

2. Oregon and Washington

3. Northern California

4. New Mexico and Arizona

5. The Black Hills of South Dakota and Wyoming

References:

Barrows, J.S., 1951. Forest Fires in the Northern Rocky Mountains. U.S. Forest Service, Northern Rocky Mountain Forest and Range Experiment Station, Station Paper 28, 252 pp.

_____, 1966. Weather modification and the prevention of lightning-caused forest fires. In Human Dimension of Weather Modification W.R. Sewell, Ed., Univ. of Chicago Press, Chicago, pp. 169-182.

Fuquay, D.M., 1960. Generator technology for cloud seeding. J. Irrigation & Drainage Div., Am. Soc. Civil Eng. Proc., 86:79-91.

_____, 1962. Mountain thunderstorms and forest fires. Weatherwise. 15(4):148-152. Am. Meteor. Soc., Boston.

_____, 1967. Weather modification and forest fires. In Ground Level Climatology, Shaw, Ed., pp, 309-325. Amer. Assoc. Av. Sci., Washington, D.C.

_____, 1974. Lightning damage and lightning modification caused by cloud seeding. In Weather and Climate Modification, W.N. Hess, Ed., pp. 604-612. New York, Wiley.

_____, 1975. Lightning Modification in Watershed Management. Ph.D. Thesis, Colorado State University, Fort Collins, Colorado.

_____, and R.G. Baughman, 1969. Project Skyfire Lightning Research. Unpub. final report to National Science Foundation, Grant No. GP-2617, 59 pp.

_____, R.G. Baughman, A.R. Taylor, and R.G. Hawe, 1967. Documentation of Lightning Discharges and Resultant Forest Fires. Research Note INT-68, 7 pp. USDA Forest Service.

_____, A.R. Taylor, R.G. Hawe, and C.W. Schmid, 1972. Lightning discharges that caused forest fires. J. Geophys. Res., 77, 2156-2158.

ICAS, 1971. A National Program for Accelerating Progress in Weather Modification. ICAS Report 15a.

MacCready, P.B., Jr., and R.G. Baughman, 1968. The glaciation of an AgI seeded cumulus cloud. J. Appl. Meteorology, 7(1):132-135.

USDA, 1968. Weather Modification for Agriculture and Forestry.

(8) Possible effects of a fifteen percent increase in precipitation on forests of the Colorado Front Range.

C. W. Barney

It is well known from dendrochronological studies that trees growing in regions of scanty rainfall show a remarkable correlation between annual precipitation and radial growth. However, in regions where drought seldom occurs, growth responses appear to be insensitive to normal minor fluctuations in annual precipitation. Thus an increase in precipitation in the spruce-fir zone would probably have little or no effect on growth of uncut closed forests. The spruce-fir forests of Colorado receive approximately 25 to 30 inches of precipitation per year but due to the low evaporative loss soil moisture is rarely a limiting factor in the old-growth forest. However, on cut-over areas where the surface soil is dried by the wind and trees suffer from high intensity insolation, an increase in available soil moisture during the critical months of July and August could significantly increase survival of newly established seedlings. Furthermore, the increased cloud cover might provide some protection to seedlings from intense solar radiation.

Ponderosa pine grows in the lowest altitudinal zone in which high forests occur. The average annual precipitation in this zone is about 16 to 22 inches. Moisture is the chief factor limiting tree growth and seedling establishment in ponderosa pine forests. Distribution of precipitation during the growing season controls the abundance of tree reproduction. Regions with rainfall well distributed through the summer months usually have adequate reproduction to maintain the stand, but where summer droughts are frequent, reproduction is sparse. Growth in diameter and height depends primarily on precipitation received during the preceding fall and winter months. During the summer soil moisture in this zone often falls to the wilting point and may remain at this level for several days or weeks. During such stress periods growth ceases. A fifteen percent increase in rainfall, if delivered in 1-3 storms during the period from late June to mid-August, might significantly improve seedling survival. An increase in late fall or winter precipitation would undoubtedly have a favorable effect on radial growth of the older trees. Any increase in precipitation in the ponderosa pine type would probably result in an increase in density of shrubs and herbaceous ground cover and thus increase competition among the plants for moisture and light.

Erosion and silting from the increased precipitation should be minimal, unless the entire increase occurs in one high intensity storm.

(9) Develop and evaluate agronomic practices as alternatives to meteorological techniques to reduce the effects of adverse weather.

R. Neild

Summer fallow, stubble, mulching, and strip cropping to conserve rainfall and soil, improved seed quality, seed protection and herbicides enabling crops to better compete at cooler planting temperature, fall vs. spring land preparation, and new varieties in crops such as soybeans, are among the numerous examples of agronomic practices that reduce the effect of adverse weather. Crop yields have increased and production has expanded to new areas. Such practices usually are relatively simple and can be readily adapted by individual farmers. Their costs and benefits compare favorably with those "implied" by cloud seeding. Emphasis should be planned upon research to develop ways for individual farmers to reduce the effect of adverse weather and to better crops with its variability.

(10) National program for evaluation and monitoring of publicly operational projects.

J. G. Ross

The South Dakota Division of Weather Modification has completed three years and is in the fourth year of a program of weather modification which is wholly financed from state monies (3/4 from the state legislature and 1/4 from participating counties). Because the weather control commission, which determines policy, desired an entirely operational project very little resources have been put into evaluation. The evaluations that have been made are favorable both from the standpoint of rain increase and hail suppression but because they are "in house" they lack the credibility that would be desired. Within the legislature of South Dakota there is a movement to require proof of the achievements of this rather considerable financial outlay. Therefore, it is necessary that some outside impartial organization with the necessary statistical capability be given the task of evaluation. It would be desirable to have such an organization brought into the planning phase of any operational project to ensure proper statistical design. This organization should be federally funded because of the importance from a national standpoint of obtaining credible information concerning the achievements of this nationally important new science. This evaluation also could be effected for privately financed projects where circumstances are practical for protection of the consumer.

On a temporary basis, the National Science Foundation could make a grant to a competent outside organization for evaluation and monitoring of the South Dakota operation or for help in designing the evaluation of any new operational project which may be proposed. Such an operation is now being planned in North Dakota.

On a more permanent basis, the USDA should be involved directly in this evaluation work because of its national importance to agriculture. This money could be made available through the experiment station system so evaluation can be made of privately financed cloud seeding for protection of the farmer consumer.

(11) Optimum application of current, or improved, weather modification techniques to agricultural problems will require a better long-range forecast.

Summarized from the Taped Discussions

Agriculturalists have long been pushing for improved long range forecasts. Weather modification could be of much more benefit if the overall crop-weather situation it would be supplementing was known. For example, we would perhaps not want to enhance precipitation in one month if we knew the next would be wet. On the other hand, if we knew the summer would be dry we might employ weather modification earlier in the season where the opportunity might be greater. The need is for seasonal or monthly long-range forecasting.

Additional Recommendations

(1) Snow Pack

D. E. Schlegel

Continue programs to enhance snow pack in the high mountain areas. These activities have proven value in increasing water storage for irrigation. The cost benefit ratio for this type of weather modification is very favorable and should be continued.

(2) Frost

D. E. Schlegel

Develop capacity to protect against radiation frost. A substantial number of crops are exposed to frosts in early spring. These frosts kill succulent young growth with fruit or flowers or in the case of herbaceous plants, kill the whole plant. Losses in such instances can be minor or almost total. These frosts occur under clear skies without wind and presumably would not occur under cloud cover. The frost conditions can be predicted at least one day in advance. They occur generally one or at the most two successive days and their prevention during that critical period can mean the difference between a crop and no crop.

D. Economic Effects of Weather Modification on Agriculture

Increases in yields expected from some possible results of applied weather modification.

Panel on Agriculture (by Henry Lansford)

Winter Wheat -

One inch of rain pre-season -- 1 1/2 - 2 bushels/acre.
One inch rain on call -- up to 10 bushels/acre.

Spring Wheat -

One inch pre-season -- 1 1/2 - 2 bushels/acre.
1° reduction in max temperature -- ?
(Spring wheat requirements for summer rainfall and temperature conflict with sorghum requirements).

Corn

One inch at planting time -- on occasion; warmer spring temperature -- small increase + 1 inch in midsummer -- 5-10 bushels/acre. -5° max. temp. on call -- 0-5 bushels/acre. Better fall dry-down weather -- 0-5 + energy; frost suppression on call -- 0-10; dry harvest -- 0-5. Increase in moisture reserve -- ?

Soybeans

One inch in midsummer -- 0-3 bushels/acre; rain at germination - emergence - benefit; low precipitation - low humidity at the same time as for corn -- some benefit.

Forage
Fruits and Vegetables
Forestry

Potential benefits that are difficult to quantify

E. Weather Effects on Various Crops as Related to Weather Modification and Public Issues

(1) Corn

Don Baker

1. Planting Period

a. This period extends from late April in the southern corn belt to late May in the northern corn belt.

b. The planting period in each local area is about 2 weeks in duration.

c. The suppression of precipitation may be required for reasons of seedbed preparation and soil trafficability.

d. The planting date is most critical and a delay of 10 days in the early planting period may reduce yields 6-10% (about 6-10 bu/a.), a delay of 10 days in the latter part of the period may reduce yields 15% (about 15 bu/a.)

e. Warm temperatures are desired and the soil and air temperatures should be 50°F. Since temperature and precipitation are more or less confounded, no statement is made concerning value of a temperature increase.

2. Silking and Tasseling Period

a. This period extends from mid-June in southern Missouri to mid-July in the northern corn belt until the end of August.

b. During this period moisture is most critical and the plant requires more than normally falls. As a result, the soil moisture reserves are extremely important.

c. The augmentation of precipitation is ordinarily more critical in the western part of the corn belt than in the east due to both the amount and distribution of precipitation. In a normal year the amount of extra water required ranges from about 0.5 inches in the east to 5 inches in the west.

d. One inch of precipitation during this period is equal to about 5-10 bu/a. Upon occasion this increase may equal 25 bu/a.

e. The moderation of temperatures is ordinarily a desirable feature and it is not necessarily confounded with precipitation occurrence. The amelioration of high temperatures is an "on call" feature and a 5°F decrease of the maximum temperature may equal 0-5 bu/a. increase.

f. Air temperatures > 85°F are undesirable. The required reduction may be about 0-3°F in the north and 3-5° in the south.

3. Maturation or Drying Period

a. For most of the corn belt this is the month of September.

b. The suppression of precipitation may be desirable.

c. The increase in yield with a drier maturation period may increase yields (0-5 bu/a).

d. The suppression of frost may be desirable. This is ordinarily not a problem in the southern corn belt but in the north it could improve yields by 0-10 bu/a. This feature is conditional and "on call".

4. Harvest Period

a. This period extends from August in extreme southeastern Missouri, but for most of the corn belt it is October - November.

b. During this period low precipitation is desirable for reasons of soil trafficability.

c. A decrease of one inch of rain may be worth 0-5 bu/a.

5. Autumn Recharge Period

a. This period extends from the end of harvest to the winter period, which may mean soil freezing.

b. Precipitation augmentation is generally desired in this period in all areas of the corn belt except the east. The reason for this is that by the spring planting period, the soil moisure reserves are at optimum levels in the eastern corn belt.

c. The increase of soil moisture reserves can be worth about 10-20 bu/a. per each inch of water. These increases in yield are conditional upon the earlier water reserve in the soil.

6. Special Remarks

a. Hail suppression is desirable from May-September.

b. Priority of the seasons with respect to weather modification activities (listed in decreasing order of priority).

1. Silking and tasseling period

2. Planting period

3. Autumn recharge period

4. Maturation period and harvest period

(2) Soybeans

Bruce Curry

This discussion of the weather modification needs of soybeans will be confined to soybeans grown in the corn belt. The needs are listed by growth and development stage with an indication in ( ) of the time range error in the region. Where available, estimates of needs and responses have been given numbers.

DEVELOPMENT STATE	TIME	NEED	RATIONALE	RESPONSE
Planting	May-June depending on location	Low precip. (Below daily ET)	1.To provide for trafficability 2.To provide optimum seed bed texture	Needs study
Germination and Emergence	1-2 weeks after planting	1. Moderate moisture(equal to ET) 2.No hard rains which produce crusting 3.Soil temp 50°F mean air temp 50°F	To produce a uniformly distributed stand of uniform sized plants	Needs study
Vegetative Development	June & Early July	Moderate soil moisture; augmentation depending on antecedent moisture & location	To produce a developed top & root system	Not known
Reproductive stage, flowering and pod fill	July & Aug.	Adequate moisture which will require augmented rainfall to make up difference between ET loss & rainfall(0-1"/wk) Max. temp 90°F??	To produce an adequate no. of pods and maximum fill. Key to yield	1-inch water equals 0-2 bu. increase. Need more info on temp.
Dry down & harvest	Sept & Oct	Low precip. humidity, less than daily ET	1.For field origins to conserve quality & energy 2.To provide trafficability at harvest	Need data
Non growing season		NATURE NORMALLY PROVIDES ADEQUATE MOISTURE		

(3) Grain Sorghum

R. Neild

Grain sorghum is a coarse grain cereal believed native to semi-arid regions of India and Ethiopia. Following rice and wheat, it is the third most important human food grain in the world. It is principally grown in the semi-arid regions of China, India, Africa and the United States. Except for exports by the U.S. where grain sorghum, called milo, is used for animal feed, most grain sorghum is consumed where it is grown. Compared to wheat, corn and rice, very little grain sorghum is involved in international trade. The U.S. is the major exporter and western Europe the major importer.

The central and southern states of the Great Plains, Arizona and California are the major growing areas for grain sorghum in the United States. Its culture, production cost, and yield are similar to corn but it has certain unique features making it better adapted to areas that would be climatically marginal for corn because of lower rainfall. Grain sorghum is more drought tolerant. It requires warmer temperature for germination and growth than corn and is more sensitive to late frost and cool weather. Its head is not protected by husks like corn so it is more subject to rain damage at harvest.

Grain sorghum requires 90 days to mature. It usually is planted between May 15-June 15 in the Central Plains - Nebraska and is harvested between September 20 - November 20. Planting and harvest are progressively earlier to the south. Following are critical periods and adverse weather factors during the growing cycle.

1. Planting to emergence -- 5/15 - 6/20
Below normal temperature - 60°F - required for germination and early growth or stand will be poor. Above normal rainfall or flooding, delays planting, results in poor seed bed, and greater competition from weeds. Grain sorghum seedlings are smaller than corn and more sensitive to weed competition.

2. Seedling establishment May 25 - June 20; below normal temperatures; frost; much above normal rainfall if subsoil moisture conditions are good; cool wet conditions favor weeds.

3. Rapid deep development and growth -- 6/20 - 7/10; below normal temperature; below normal precipitation; hail.

4. Boot stage (floral bud development) -- 7/10 - 7/25; below normal rain; below normal temperature; hail; moisture stress critical.

5. Heading (reproduction) -- 7/20 - 8/20; below normal rainfall; below normal temperature; maximum temperature core 95°F; dessicating wind; hail; moisture stress very critical.

6. Grain filling and maturation -- 8/20 - 9/20; below normal temperature; much above normal precipitation in September; below normal precipitation; frost.

7. Harvest -- 9/20 - 11/20; above normal rainfall; early frost before; below normal temperature. Delay in freeze -- later than 10/15; snow.

(4) Hard Red Spring Wheat

J. Ramirez and J. Ross

In the semi-arid to sub-humid hard red spring wheat areas of the Great Plains, additional amounts of rainfall after emergence through the period just prior to harvest will be generally beneficial to final yields. This is illustrated in Figures 1 and 2 which also show that the yield returns from the additional rainfall is maximum in the heading, bloom and milk stages of the wheat growth. These phenological stages generally occur in June and early July in the northern Great Plains. Previous studies suggest that an additional inch of growing season rainfall can increase spring wheat yields by about 2 1/2 bushels per acre in the northern Great Plains.

During the harvest periods of spring wheat, however, generally during the last two weeks in July through August, the suppression of wet day conditions is desirable both in terms of field trafficability but as important, in terms of preserving grain quality of the harvest.

Spring wheat yields have been found to be strongly correlated to stored soil water accumulated through the off-growing season. Past independent regression analyses in the literature suggest that an inch of stored soil water contributes an average of 1 1/2 to 2 1/2 bushels per acre. For this reason, the augmentation of preseasonal precipitation during the fall period after harvest completion and through ground freeze up (late September through November) would be desirable. During the latter winter months, however, it is recommended that precipitation augmentation be only attempted when the soil water storage before ground freeze up is deemed insufficient for optimum seedling start in the following spring. On the other hand, if adequate soil water has been stored by the fall and early winter, precipitation for the following spring, the suppression of late winter and early spring precipitation may even be desirable.

Wheat is basically a cool season crop. Wheat yields generally benefit from lower mean temperatures throughout the growing season except during seed germination. Attempts to moderate the daily maximum air temperatures in the midsummer months of June and July will be beneficial to the wheat crop.

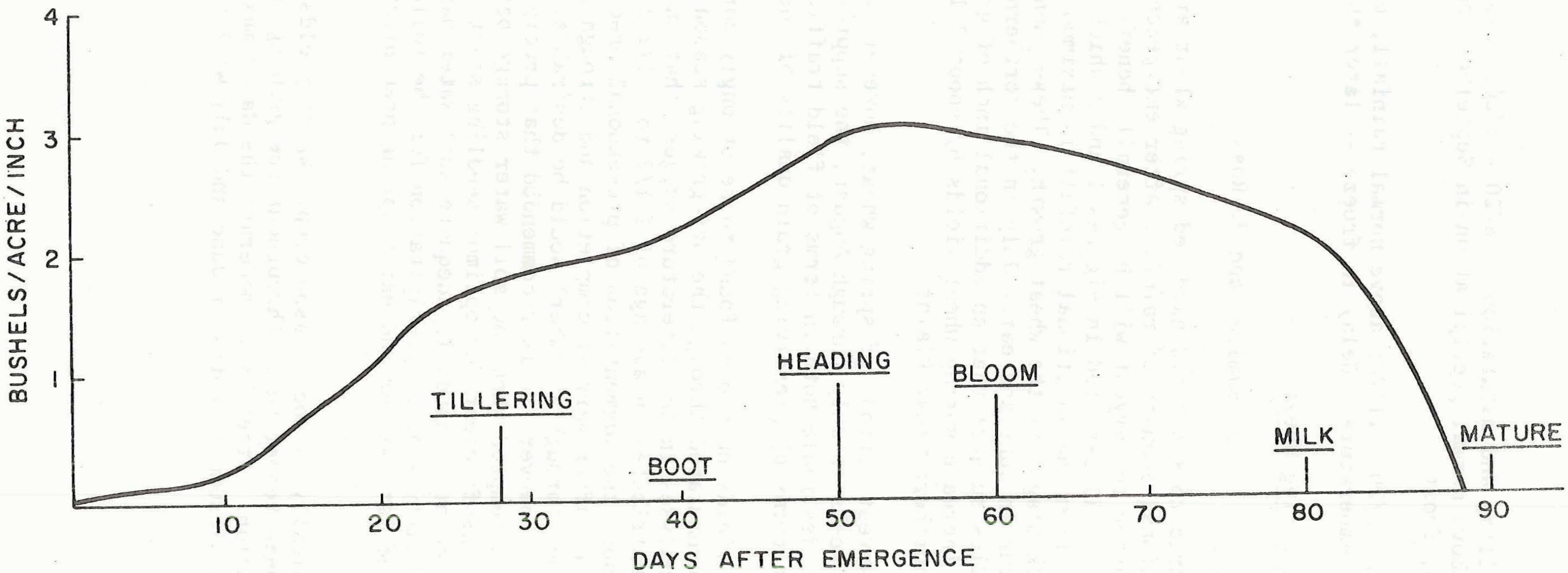

Fig. 1. Estimated average effect of an added inch of growing season rainfall at various growth stages on spring wheat yields in the Northern Great Plains.

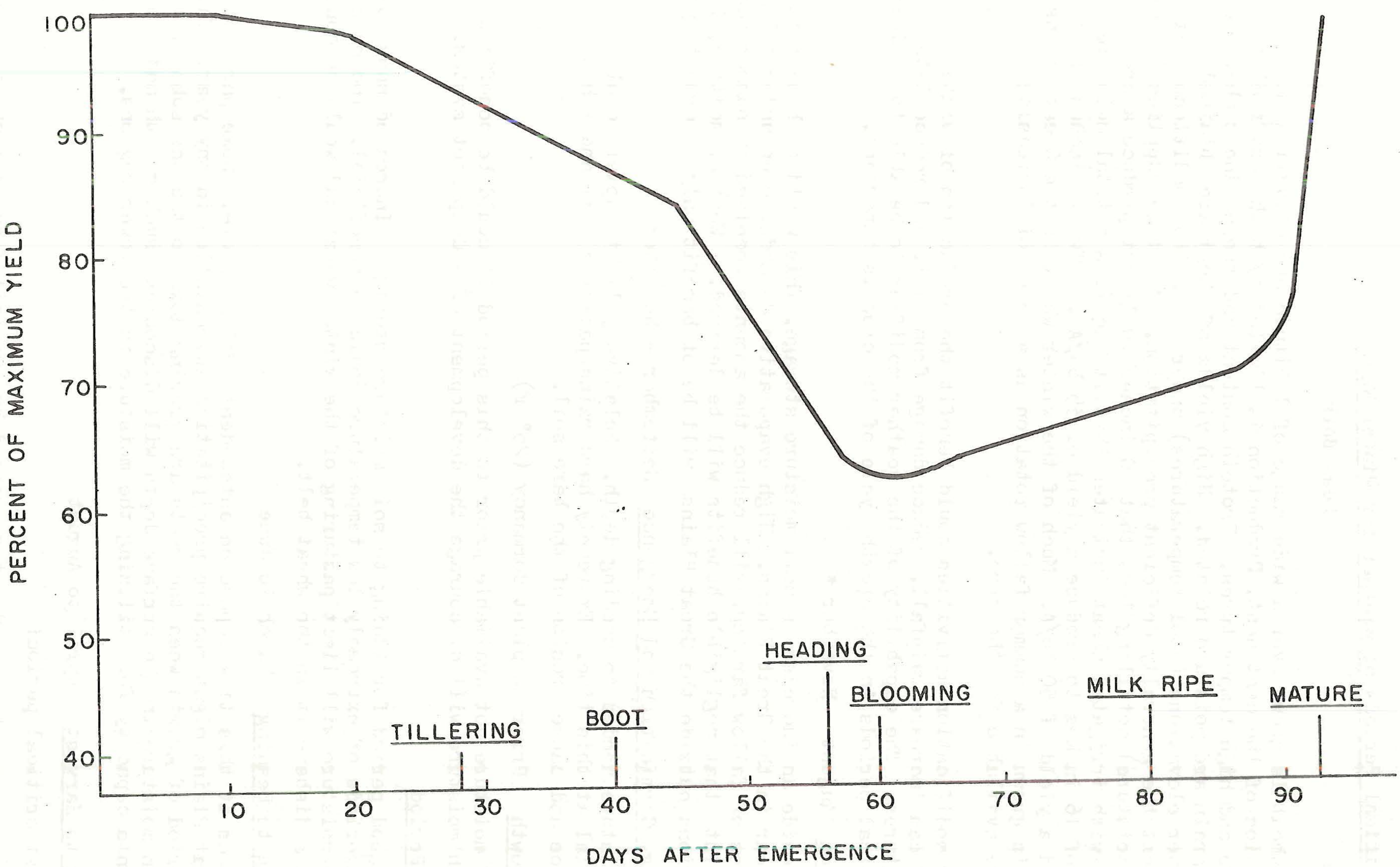

Fig. 2. Effect of water stress at various growth stages on grain yield reduction in wheat.

(5) Critical Periods of Weather for Winter Wheat

Dean Bark

Winter wheat is grown over a wide range of latitude and elevation in the mid-section of the continent. Production is limited by both insufficient moisture and high temperatures. Protein content and the hardness characteristic of the grain are moisture related. High yields of wheat are obtained in the higher elevations (cool temperatures) under irrigated conditions that supplement the generally deficient precipitation. Moisture supplies (precipitation + soil moisture) totalling less that 10 inches will not produce a crop. Studies with irrigated wheat indicates that it requires a total moisture supply of 16 inches to produce a yield of 35 bu/A. Twenty inches of moisture produced a yield of 50 bu/A. Much of the winter wheat in the Great Plains region is grown in a summer fallow rotation as a means of increasing the moisture available for the crop.

Weather modification activities could benefit the production of winter wheat if they can increase rainfall, reduce damage from hail, and reduce late spring temperatures. The capability of the weather modifier to be able to produce at critical periods in the growth cycle of the crop is important.

Preseason August - November *

Provide an increase is soil moisture storage. This would be beneficial every year in the Great Plains. High evaporative demands, even under tillage practices of fallow farming, will reduce the amounts received in summer months to a point that negligible benefits will be derived. Weather modification for regions outside the Great Plains will be of benefit only in drougth years.

Planting, Germination and Emergence September - November

Moisture needed to seeding depth. Relatively light showers could be beneficial at this time. Extremely hard rains pack the soil and inhibit emergence and cause erosion of the bare soil.

Fall Growth Prior to plant dormancy (25° F)

If moisture not available prior to this period it could be beneficial. Too much moisture will discourage the development of a deep root system.

Winter Period

A good period for adding to soil moisture storage. Increased snow cover during periods of extremely low temperature could be beneficial. Too much surface moisture will limit pasturing of the winter wheat and would be considered a disbenefit in the wheat belt.

Jointing to Heading March to June

Needs at this time depend on antecedent soil moisture. Some parts of the Great Plains might require precipitation augmentation in any year. This is a period of growth when the roots are growing down to tap the subsoil moisture. Too much moisture in the surface depth will discourage such growth and limit the plants capacity for utilizing the moisture in the lower regions.

Heading to Harvest April to August

Most critical period!

Hail can negate any advantage gained by precipitation augmentation. Hail suppression activities would have top priority in the western regions of the wheat belt.

Moisture needs in this period are variable. If soil moisture is not available, precipitation augmentation will be required to provide moisture for filling the grains. Test weight and yield will be low if inadequate. If precipitation is too great, the protein content will be low, and lodging may occur.

Cool temperatures are needed at this time. Early season high temperatures are detrimental. This probably accounts from yield reductions in the southern portion of the wheat area. A reduction of these temperatures of 5° could produce a yield increase of 10 bu/A if moisture was available.

Precipitation reduction in the more humid eastern portion could lead to a beter utilization of nitrogen fertilizer supplies.

Harvest Time June to August

Dry weather is needed in this period. It will last approximately 1-2 weeks in a given area. Delayed harvest results in loss of both yield and quality.

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* Time periods given represent the range from the northern and high elevation portions of the wheat belt to Texas. At any one location, the time periods are considerably shorter.

(6) Forage and Weather

W. Decker

Forage, as used in this statement, are grasses and legumes grown for hay, halage or pasture and used as livestock feed. These forages are grown in all humid and subhumid regions of the U.S.

SEASONAL	WEATHER NEEDS	CORRESPONDING CALLENDAR PD.
1. Initial cool season growth period	Temperatures in excess of 50°F. Adequate water supply from rain or soil moisture ET rates .35 to 1.00"/wk.	In Gulf Coast States winter months March-April in mid-central states May in the North.
2a. Summer growth for pasture	Temperatures below 90°F-95°F. Adequate rain, for ET; rates from 1 to 2 inch/wk. Heavy and prolonged rain a disadvantage for livestock harvesting.	April-September in south, June-August in north.
2b. Summer growth for hay.	Temperatures below 90°F-95°F adequate rain for ET rates 1.25 to 2.25"/wk. Occasional dry periods for harvest. one inch rainfall increase should produce 1/3 T increase of yield for legumes.	June-August in north in south fall through winter.
3. Terminal cool season	Temperatures above 50° for continued growth; water used .5 to 1.5"/wk.	In south fall through winter in north until temperatures fall below freezing.

(7) Fruit Crops

D. E. Linvill

Fruit crops are grown throughout the world intermingled with other crops discussed in this report. Since trees are perennial plants, weather conditions in summer, winter, spring and fall influence yield quality of the crop. There are critical periods during the crop year during which weather modification can directly affect production. Each crop is a distinct entity. Thus, no attempt will be made to state exact calendar dates for critical periods in each crop, nor will specific crops be cited in all cases.

One critical period is the dormant stage which usually occurs during the winter months. During this time extreme low temperatures can kill tree buds. Critical minimum temperatures are known for each crop. A moderation of the minimum daily temperature to keep it above the critical temperature can mean the difference between success or crop failure.

A second aspect of winter time temperatures is the range of temperatures during freeze-thaw periods. If maximum daily temperatures are sufficient to deharden the buds, subsequent freeze conditions will kill the bud and reduce crop yield significantly. Thus, a lowering of the maximum temperature during a freeze-thaw episode can result in improved crop yield.

The effect of frost upon tree crops can be seen at both the blooming stage and at maturity. A frost that occurs when the crop is in bloom will result in flower drop. The reduced number of flowers and set flowers means that the yield will be reduced proportionally. Both advection frosts and radiational frosts can lead to yield losses. Weather modification that raises nighttime temperature minimums above the frost temperature will directly influence yield.

As the crop matures, quality rather than yield will become an important component. Early fall frosts occurring before the crop is fully mature will reduce the quality of the fruit. It can also reduce the yield by causing premature fruit drop and spoilage. Although part of the crop may be salvaged through rapid work, the decrease in quality significantly lowers the profit from the crop. Frost protection at maturity will help both yield and quality.

Just as frost temperatures influence quality, extremely warm temperatures ($T_{max} > 90°F$) can also reduce quality. High daytime temperatures will increase moisture stress on even well-watered tree crops. Reduction of temperatures above about 90°F will help the crop by reducing transpirational demands upon the plant. Weather modification through a direct effect upon maximum temperature or upon the radiational load on the plant can improve quality. Although radiation decrease during summer may be important when temperatures are high, a radiation increase at harvest time can be beneficial. At maturity many crops such as

The panel specifically recommends:

1. The immediate formation of a Presidential Commission to
   a. Assess weather modification status and potential as well as possible benefits and disbenefits.
   b. Formulate a rational and coherent national weather modification policy.

2. The USDA immediately initiate and support research relating to meteorological aspects and socio-economic aspects of weather modification.

2. Recommendations for Research

The following research recommendations for weather modification were identified by the panel as those likely to further the utility of weather modification for agriculture.

a. Conduct a major experiment with convective clouds in both the corn belt and the High Plains to define potential for rain alteration, and hail suppression. We encourage the sound scientific pursuance of HIPLEX.

b. Conduct demonstration experiments for cloud changes in special agricultural need areas.
   1. Cloud layer dissipation.
   2. Cirrus cloud formation and increase.

c. Perform technology assessments of major proposed weather changes.

d. Ascertain impacts of inadvertent weather modification on agriculture, and effect of agriculture on weather and climate.

e. Investigate, by models and analogs, macro and mesoscale interactions of large area weather modification projects.

f. Develop long range (weeks to months) prediction skills for monthly and weekly precipitation.

g. Initiate studies to estimate the potential for a rainfall modification in extreme events, (Droughts and heavy rain-flood conditions).

h. Seek definitive investigations of the economic value of weather modification and the legal, social, and ecological aspects.

i. Pursue a variety of climatic studies and analyses of past weather modification data to establish transferability and specific applications for agriculture.

j. Seek innovative concepts to alter micro-climate, fog, etc.

C. Approach and Background Basis for Panel Deliberations

It soon became clear that the task for this panel could not be accomplished in the time available if one large weather modification panel met. It was decided to split into two sub-panels.

Sub-panel A tackled the task of evaluating the field of weather modification now, and considering its prospects. Although the modifications considered were limited to those of agricultural significance, this was, as it turned out, not a significantly limiting factor. All possible types of weather modification on all scales were considered. Thus, a basis for an evaluation of the role that weather modification might play world-wide was established.

Sub-panel B primarily considered in detail weather modification in relation to the agricultural problems of the Corn Belt and the High Plains. This placed emphasis on this critical world food producing area. The present and future capabilities of the technology for this area were thoroughly assessed. The greater geographical emphasis allowed detailed consideration of the other important issues for this case, such as other impacts (environmental, societal, etc.). Costs and additional needed research in this area were also considered.

Certain comments, questions, and key issues were raised in the participant's opening presentations on July 16. These served as a basis for starting panel deliberations. Those points mentioned by two or more people are listed below.

1. Establish true direct and indirect values and impacts of weather modification (Peterson, Warburton, Changnon).

2. Application of weather modification in "fire-fighting" type modification (droughts): it would be good, is it good and should it be evaluated? (Shaw, Droessler).

3. Need to be inventive in weather modification (Linvill, Gray).

4. Weather modification is still an infant technology that needs its utility defined (Dennis, Changnon).

5. Although in its infancy, its future is optimistic (Hosler, Simpson, Changnon).

6. There is a need for experimentation with rain in the midwest and High Plains (Neild, Changnon).

7. Evaluation of weather modification is a key issue for agriculture (Curry, Ramirez, Ross).

D. Status and Prospects for Weather Modification Useful to Agriculture

Agriculture is a world-wide pursuit. However, the resources available to the weather modification panel were not sufficient for a complete assessment of the world-wide problem. However, it was felt that with the expertise that was assembled, it would be a significant contribution to consider the meteorological, agriculturally significant, "variables" and their susceptibility to modification, both now and in the 10 to 20 year time frame. Assessing the agricultural susceptibility to weather modification then becomes a matter of defining the significance of these "variables" for the agriculture of any particular region of interest. The conclusions are summarized in Table 2. All "variables" which it was considered might be influenced and which were thought to have significance for agriculture are listed. The group then evaluated how many out of a total of 10 knowledgeable meteorologists would concur with the stated conclusion regarding our ability to modify the "variable" within the stated time frame. It should be noted that the estimates for the 10 to 20 year period are based on the assumption of adequate (much above current) levels of support to develop the technology. At the request of the agriculture panel figures for the possible amounts of change and area affected are included for the modifications with good potential anticipated. It should be noted that, in keeping with the structure of the deliberations, the amount changes and area affected apply to the average single event. Total impact in an area could be obtained by convolution with the meteorological opportunity.

A more complete analysis was conducted for the corn belt and high plains areas of the U.S. the areas being selected because of their significance to the national economy and world-wide food supply. Tables 3 through 6 indicate the best judgement of the panel regarding changes that can be induced now, and those we will be able to induce in 2000. Note that these are area average effects over the season in these regions. Precipitation modification, hail decrease and radiation modification are examined.

On the high plains slight but agriculturally significant precipitation increases have been obtained from seeding small cumulus clouds. The magnitude of this effect over an area is not well established. It is small compared to the overall variability of precipitation and it is not certain that the results apply to regions of the plains outside those in which the experiments were conducted. Costs of an operational program for precipitation enhancement are around 10 cents per acre.

As far as our abilities to modify the growing season weather now are concerned, it is clear that we have almost no knowledge of the possibilities in the corn belt. The definitive experiments have not been conducted here.

TABLE 2. STATUS AND PROSPECTUS SUB-PANEL A

Modified Variable	Enhancement				Dissipation			
	Now	10-20 yr	Amt. Chg.	Area mi^2	Now	10-20 yr	Amt. Chg.	Area mi^2
I Clouds								
1. Cold Stratus	No(8)	Yes(7)		1-1000	Yes(10)	Yes(10)		1-1000
2. Warm Stratus	No(10)	No(5)			No(8)	Yes(9)		
3. Fog, Cold	Yes(10)	Yes(10)		1-10	Yes(10)	Yes(10)		1-1000
4. Fog, Warm	Yes(10)	Yes(10)		1-100	Yes(10)	Yes(10)		.1-1
5. Fog, Artifical (for temp. control)	Yes(10)	Yes(10)		1-10	N/A	N/A		
6. Contrails	Yes(10)	Yes(10)		100-1000	No(10)	No(10)		
7. Cirrus	Yes(5)	Yes(10)		100-1000	No(10)	No(8)		
8. Carbon Black	No(10)	No(6)			N/A	N/A		
9. Aerosol	Yes(7)	Yes(10)			N/A	N/A		
II Convective Precip.								
1. Isolated Sm.	Yes(7)	Yes(10)	100%	10-100	Yes(5)	Yes(8)	100%	10-100
2. Isolated Lg.	No(6)	Yes(7)	15%	100-1000	Yes(5)	Yes(8)	15%	10-1000
3. Squall Lines	Yes(5)	Yes(6)	20%	100-10,000	No(8)	Yes(5)	20%	100-10,000
4. Nocturnal	Yes(5)	Yes(6)	100%	100-1000	No(8)	Yes(5)	100%	100-1000
5. Imbedded Cyclonic	Yes(9)	Yes(10)	30%	300-6000	Yes(8)	Yes(10)	< 5%	300-6000
6. Imbedded Orographic	Yes(9)	Yes(10)	20%	300-6000	Yes(8)	Yes(10)	20%	300-6000
III Stratoform Precip.								
1. Orographic	Yes(10)	Yes(10)	10%	100-3000	Yes(10)	Yes(10)	10%	100-3000
2. Cyclonic	No(10)	No(6)			No(10)	No(6)		
3. Cloud Water Collection	Yes(10)	Yes(10)			N/A	N/A		
IV Hazards								
1. Hail	Yes(5)	Yes(7)	?	100-60,000	Yes	Yes	30%	100-60,000
2. Lightning	Yes(7)	Yes(9)	?	40,000	Yes(7)	Yes(9)	40%	40,000
3. Erosion-Wind Gradient	No(10)	No(10)			No(10)	No(10)		
4. " -Water, Drop Size	Yes(5)	Yes(7)	?	10,000	Yes(5)	Yes(7)		10,000
5. Wind-Hurricane	No(5)	Yes(6)			No(6)	Yes(6)		
6. Tornado	No(10)	Yes(5)			No(10)	Yes(5)		
7. Blowdown	No(5)	Yes(5)			No(9)	Yes(5)		
8. Floods-Synoptic	No(10)	No(10)			No(10)	No(3)		

Table 2. (Cont'd)

Modified Variable	Enhancement				Dissipation			
	Now	10-20 yr	Amt. Chg.	Area mi^2	Now	10-20 yr	Amt. Chg.	Area mi^2
9. Floods-Mesoscale	No(9)	Yes(6)			No(9)	Yes(6)		
10. Drought	No(10)	No(10)			Yes(5)	Yes(6)		
V Other								
1. Albedo	Yes(5)	Yes(10)			Yes(5)	Yes(10)		0-00
2. Surface Roughness	No(6)	Yes(6)			No(6)	Yes(6)		
3. Topography Changes	No(6)	Yes(5)			No(6)	Yes(5)		10-100

TABLE 3

AVERAGE GROWING SEASON (APRIL-SEPT.) CONDITIONS OVER AN AREA - NOW

		CORN BELT	HIGH PLAINS**
1. Rain	Increase	?	10% ±10
	Decrease	?***	?***
	Character	?	?
2. Hail Decrease			30% ±40*
	With added rain	?	yes
	With no rain change	?	yes
	With rain decrease	no	no
3. Radiation			
	Local Temp. increase (night or day)	?	?
	Local temp. decrease	?	yes, 8°C

* Based on Dakotas, West Texas and Africa. NHRE and Alberta hail results inconclusive but continuing.

** Most evidence from Dakotas.

*** Limited evidence of possibility from Project Whitetop.

TABLE 4

PROSPECTUS* FOR 2000 OF AVERAGE GROWING SEASON CONDITIONS OVER AN AREA

	CORN BELT		HIGH PLAINS	
	% Change	% Confidence	% Change	% Confidence
Rain Increase**	10	75	15	75
Decrease	10	50	10	50
Character	Feasible		Feasible	
Hail Decrease**	50	50	75	75
Radiation				
Cloud cover increase	50**	25	50	25
Cloud cover decrease	50	25	50	25

* Given adequate growth funding, but non-NASA scale.

** Convective manipulation more feasible on time(day) and space(meso) scale.

*** Percent of the time desired.

TABLE 5

COLD SEASON STATUS (October-March)-NOW

Area Average Changes

PRECIPITATION

PRECIPITATION	CORN BELT	HIGH PLAINS DIRECT	MTN. SNOWPACK FOR TRANSPORT OF WATER TO HIGH PLAINS
Increase	10%[±5%(?)]	10%(+20%,-5%)	10%(+20%,-5%)
Decrease	10%[±10%(?)]	10%(±10%)	10%(±5%)
Redistribution	yes	yes	
Character	yes	yes	
RADIATION	NOT APPLICABLE		

TABLE 6

PROSPECTUS* FOR 2000 OF AVERAGE COLD SEASON CONDITIONS OVER AN AREA

	CORN BELT		HIGH PLAINS DIRECT		MTN. SNOWPACK FOR TRANSPORT OF WATER TO HIGH PLAINS	
	Percent Change	Confidence	Percent Change	Confidence	Percent Change	Confidence
Precipitation in						
Increase	15	75	15	75	15	90
Decrease	10	50	10	75	10	75
Redistribution	on occasion	90	on occasion	75	on occasion	90
Character	"	100	"	100	"	100

Radiation

Increased cloud cover - 50% of time desired - 50% confidence.
Decreased cloud cover - 50% of time desired - 50% confidence.

* Given adequate growth funding, but non-NASA scale.

An ability to modify hail damage has been rather strongly suggested by experiments on the plains, although the effect may occasionally have been to increase hail. The additional cost for a hail suppression program over that of a precipitation enhancement program, when the two are conducted together, is 1 to 2 cents per acre.

A limited ability to decrease daytime temperatures is considered to exist based on ice nucleus seeding of ice supercooled atmospheric layers. Costs are estimated at 5 cents per acre per month for seeding 5 days a month over a 3,000 mi^2 area.

In the current time frame an ability to change cold season precipitation is indicated. Definitive studies show a potential for creating considerable additional water for irrigation by snowpack augmentation. Experience shows the cost of this water is around two dollars per acre foot. Precipitation augmentation techniques during the cold season on high plains and in the corn belt are considered to exist. The cost on the plains would be about five cents per acre.

By the year 2000, given adequate growth funding, the panel projects that we could develop the ability to make changes that would substantially enhance agricultural production.

E. Proposed Investment in Weather Modification Research

Perspective. As we have noted before, for a science with such tremendous potential benefit to society, weather modification is still in its infancy thirty years after its inception. The meteorological community has long recognized the potential and strongly supported these studies. Figure 1 taken from a paper "The Paradox of Planned Weather Modification" published in the January 1975 issue of the Bulletin of the American Meteorological Society depicts the evolution of federal weather modification research funding and compares this to that recommended by the National Academy of Sciences in reports in 1966 and 1973. It is clear that funding levels are falling drastically behind recommendations.

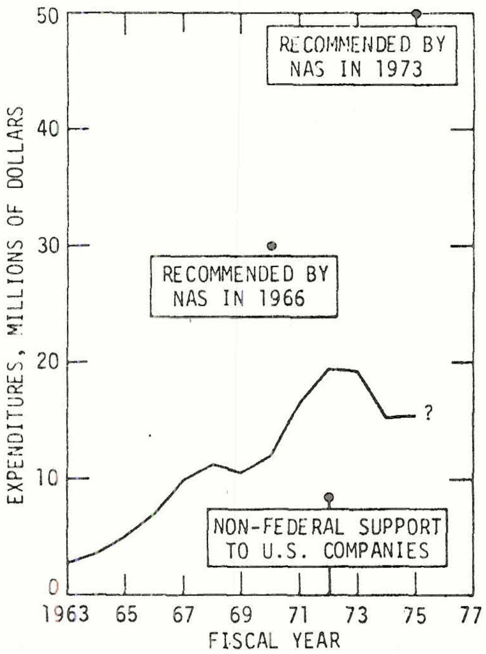

Fig. 1. The annual federal expenditures for weather modification plus levels recommended by National Academy of Sciences and the FY72 non-federal support to American commercial firms for weather modification.

The weather modification panel evaluated the funding levels which would support research and development of various weather modification activities of benefit to agriculture. To develop technologies for cumulus cloud modification (precipitation enhancement and hail suppression during the growing season) a ten year total of 130 million dollars would be required. An initial funding level of 10 million dollars a year would increase rapidly at first and then level off to 20 million. A similar program would be needed in the corn belt. Even though there is now a useable technology for orographic cloud modification an additional 5 to 10 million dollars a year in research monies is needed to enhance the technology and extend its applicability to other areas such as the large scale orographic clouds that form on the more gently sloping plains. Seed money of 3 to 5 million dollars a year is required for a ten year effort in modeling synoptic and mesoscale systems to investigate their modification potential, both by conventional modification technologies and also more innovative ones such as carbon dust.

If funding remains at its current inadequate levels, results will not meet the potential indicated herein. As ye sow, so shall ye reap.

F. Ecological/Environmental, Socio-Political and Legal Impacts

This workshop was strongly reminded that many people believe the many inadvertent impacts of weather modification are an almost insurmountable barrier to its widespread implementation. Experience, for example, in Israel, Australia, and the widespread application in the U.S., suggest that these barriers can be fairly readily overcome in some circumstances. If the benefits are perceived as outweighing the disbenefits, they will be tolerated.

Table 7 lists possible inadvertent aspects of weather modification to enhance snowpack, optimize precipitation and cloud cover. An assessment of the severity of the impact problem is given. It should be noted that many of these problems will benefit from development of adequate decision mechanisms.

TABLE 7. PROBABLE IMPACTS OF THREE TECHNOLOGIES ON "OTHER ISSUES"

	Impact	Snow Aug.	Precip. Aug./Hail	Cloud Cover
Ecol/ Env.	AgI Effects		(I)	
	Air Chemistry and Effects on Bio		(I)	
	Hydrology, Run-off Peaks		(S)	
	Avalanches*	(S)		
	Downwind Precipitation		(M)	
Socio-Political	Transportation	(M)		
	Local Disbenefits	(M)		
	Community Action		(L)	
	Environmental Impact Statement		(S)	
	Conflicts of Interest (Heterogeneity of Weather Needs)		(L)	
Legal	Water Rights		(M)	
	Interstate Conflicts		(M)	
	International Conflicts		(M)	
	Liability		(L)	

Key to Assessment of Problem or Impact Significance:

I = Insignificant
S = Slight
M = Moderate
L = Large

*Slight if you assume protective measures adequately taken. Many of these problems will benefit from development of adequate decision mechanisms.

V. PARTICIPANT'S STATEMENTS

Opening statements by the participants are presented here in order of presentation. A number of speakers have submitted written versions of their presentations which are included below. In cases where the presentations have been abstracted from the taped proceedings, this is indicated by a star by the individual's name. In several cases the quality of the taped proceedings was not good and it was difficult to transcribe all of the presentation as it was given. Thus, some editing has been performed on some of these presentations. Limitations in time have prevented the review of this version of the transcripts by the individuals involved. The editors have attempted to retain the speakers words as far as possible.

* Speaker's presentation edited from the taped proceedings.

VI. CURRIE DOWNIE, PROGRAM MANAGER FOR WEATHER MODIFICATION, NATIONAL SCIENCE FOUNDATION

We hear from Jack Barrows that there was an effort back in 1968 to try to define the potential of weather modification for agriculture. This was a good start and I think we should build on it. We have made considerable progress since then, but I think that the 1968 report is a good starting document for this workshop, which is part of our AGRIMEX effort in the NSF weather modification program. Some of you at the meeting in Boulder earlier today heard that we have several different efforts going in agriculture. One of them I might mention is the National Academy effort that is just starting. This is a study under BARR -- the Board for Agriculture and Renewable Resources. It has seven sub-tasks, one of which is to look at weather modification and its implications for agriculture and potential support for agriculture. Another is climate, the longer term impact of weather variations on agriculture, and there are several panels that deal with agriculture directly: cultivars, pests, soil erosion, agriculture in less developed countries, and various management techniques that can be applied to the problems. Bill Hougart is the National Academy staff man on this effort. Sylvan Wittwer is one of the PI's along with Phil Ross. The key man in charge of the effort is Wayne Decker and I expect that most of us will be hearing a lot more from Wayne Decker as he gets his effort underway.

This workshop was set up as a separate effort, but it is expected that our results will feed directly into the more comprehensive National Academy study. Some of the areas that we are interested in are, of course, precipitation enhancement, hail suppression, ameliorating temperature extremes and severe winds, etc. There are many different possibilities. People have speculated for quite some time on how weather modification could benefit agriculture. But, I think here we are trying to collect all these ideas. This will be, I expect, in the beginning largely in the nature of a brain storming session. All your ideas are welcome. Let us take a look at them and as we go on, we'll evaluate and refine them and procede from there.

I would like to mention a little more background information. The Subcommittee on Climate Change of the Domestic Council's Environmental Resources Committee, which operates out of the White House, held a meeting in Washington in mid-May on the federal role in weather modification. What is the role of the federal government in weather modification? This particular meeting was open to the public. It was an attempt to get opinions from the non-federal sector as to what these people felt were the roles of the federal government. Some of the results of this meeting are rather interesting to us. One of the statements that got in the record is that weather is the primary determinant of agriculture -- courtesy of Sylvan Wittwer. Stan Changnon, talking about internal re-focus of research by the federal government, said "I think it should begin with the user concept." The question is who needs and is vitally concerned with weather modification? Agriculture is the prime user of weather modification. My major recommendation from an organizational standpoint is therefore, that the agriculture community, in the case of the federal government the Department of Agriculture, must become significantly involved in weather modification. Charlie Anderson after the meeting wrote a letter saying that "agriculture is the major potential benefactor of weather modification. The Department of Agriculture must become involved in weather modification."

One of the things that we are hoping to do here is to collect information. We need statistics on the economics of what is involved and on the potential and so forth. In this respect I have some information from Stu Borland at the NHRE on hail losses broken down by crop, and by state. These are the states with $10,000,000 of losses or greater and the crops involved. I think this is the type of information we are interested in to start with. To get some real solid facts on what the effects of weather are on agriculture, what are the losses for example, as a result of the drought last year? What are the losses from wind damage, from soil erosion? I think there is a lot to do in this area.

We are anticipating a report out of this workshop, and there are several characteristics of the report that we would like to see. First of all, it should assess and evaluate the potential impact of weather modification on agriculture. We should look at all phases, not hold back anywhere. Any information on this would be worthwhile and welcome. Secondly, from my own standpoint, from the standpoint of the NSF and other research oriented organizations, we would like a list of research opportunities, where should we concentrate on research for the future, and some idea of the priorities. If precipitation enhancement is the big thing, we should, of course, be working in this area. I expect this document will generally lay the groundwork for a big push in this area, but first we need a good study. Hopefully, we can take this to our agencies, take it to Congress, to the users -- the users being the federal agencies, NSF. Hopefully we can get agriculture interested. As you know, some of the states are involved now in weather modification, hail suppression, for example, in South Dakota where the various counties are involved. The agricultural extension stations, the farmers themselves, and the agri-business are all potential users. What we hope to do here is set something in motion that will go a long way toward flushing out the potential of weather modification and provide some idea of where we go from here and how.

Vii. SYLVAN WITTWER*, CHAIRMAN AGRICULTURAL EXPERIMENT STATION, MICHIGAN STATE UNIVERSITY

My interest is traditionally not in weather modification, but I think I see the importance of an effort in this area. It is worthy of some time in terms of pulling together a group that I think can do something that will be significant as far as the agriculture is concerned in this nation and perhaps on a global basis.

In terms of weather modification research, we don't begin with a vacuum. Jack Barrows has mentioned the effort that transpired back in 1968 in which the USDA with the state experiment stations and other interested people put out a document as one of the 34 task forces. This dealt with weather modification and recommendations relating thereto. The report of the NAS, the National Academy of Sciences, in 1966 in which Gordon MacDonald and perhaps others in this room participated in that effort. Then my good friend Tom Malone and that National Academy effort out of the Comission on International Relations with respect to weather modification. I think that as we look at that which Currie Downie has indicated is important for his agency, we need to look at those documents and what they recommended. Some of those still stand in terms of the importance today.

We're not in a vacuum also in terms of the North Central region. There has been very little weather modification work transpire here, remember we're talking of the corn belt which is the bread basket of the nation, at least part of it. I see Stan Changnon down there is in agreement with me. We've got in this area a North Central regional committee dealing with climatic resources in the North Central region. We have many representatives of that committee here at this particular workshop,Dean Bark, Don Baker, Dale Linvill, Stan Changnon, Wayne Decker, Bob Shaw, Juanito Ramirez, Bruce Curry, Ralph Nield, Champ Tanner. We have a research committee which is financed from regional research funds through the state agricultural experiment stations. It deals with one aspect of this, an assessment of weather modification activities in the North Central Region. There is somewhat of a base here to build this workshop on. We're pleased to have two folks here from the ISWS, they are going to have a considerable input. I might indicate that this group that we speak of in the North Central region, where there has been very little weather modification work outside the ISWS, that it is high time we took a look I think at where a lot of the food is produced in this nation in terms of what weather might be doing. I will repeat what I have stated, and I think I can defend it, I think that the most determinant factor in crop productivity is that of the weather and climate. It is time that we began seriously to consider this very simple reality.

Seeing Henry Lansford back there I am reminded of the Belaggio Conference in June sponsored by the Rockefeller Foundation. An international group was assembled to consider the tough subject "Climate Change, Food Production, and Interstate Conflict". I think copies of that report are now available. It is very interesting in terms of a base for what we might think of in this particular workshop. Currie Downie mentioned the current National Academy effort which is with the Board on Agriculture and Renewable Resources. Seeing Larry Tombaugh here and Currie Downie who have

have been very supportive of this, it is through them that we are engaged in this effort which deals with the impact of climate change on food production and productivity of other renewable resources. It is an extremely important area. The Chairman of this group is Wayne Decker. He may want to talk about that with some of the folks here, a very important effort. Billy Hougart is the staff officer with the National Academy that is working with the committee in setting this up.

I think it is timely that this workshop be held. There has been interest in at least two of the foundations. I see Eric Walther here from the Kettering Foundation. I note the interest of the Rockefeller Foundation. There is a good base here for action.

Another study that is in progress which we should refer to as background for this workshop is going on in two segments. This is the so called "President's Food and Nutrition Study", an assignment given to the NAS by the President. It asks the Academy to work with agencies within government including USDA, HEW, EPA, FDA, and the Department of the Interior, all having to do with food production. The object is to come up with a program of research and development to assure the food supply of this nation and that of other nations. That is not a small order. Weather is going to be an important part of that. Weather modification is going to be a component in that study. I should indicate that one workshop has been held, another will be held in the latter part of this month. We intend to have a report to the agencies and to the President by the first of November, an interim report. There will then be a longer term, more deliberative study, a two year effort.

The point that Currie Downie mentioned with respect to hearings by the domestic council is also another evidence of interest within agencies in the government, that have power and influence in determining policy. The domestic council is one of those.

I think it is interesting that in the May 9th issue of Science, which delt with food, there was only one article which delt with weather, that of Louis Thompson. In the article I wrote I mentioned it, I didn't ignore it, but I think this matter of weather and climate modification is not receiving the attention it should in terms of the possible impact on food production.

Interestingly there were congressional hearings held during the week of June 25th. There will be additional hearings held in September. These were not by the Agricultural Committee of the Senate and the House, but by the Committee on Science and Technology. They are interested in Food and Agriculture and Nutrition. I appeared at one of those hearings and I did mention weather modification, which is a very important part of the total food picture.

I should point out that last week there was held in Kansas City, Missouri, a very large working conference sponsored by the Department of Agriculture. The Secretary was there, several Assistant Secretaries were there. The topic was research to meet U. S. and world food needs. One of the travisties was that nothing was mentioned with respect to weather modification, climate was on the list but only in terms of changing climatic patterns. This conference focusses on the more immediate issue, that of weather modification.

As we look at the workshop here in the days that will follow, in the agricultural component of this, and I will speak to that just for a moment, we need to look to areas of agriculture where weather modification can have an impact. I am speaking to the agriculturalist, most of whom I contacted personally by telephone. As we look at doing something that the agencies want, and Currie Downie referred to this . . . he wanted a report showing the possible and potential impacts of weather modification on agriculture. He also mentioned weather modification in terms of research oppotunities and where are the priorities.

We must think about who our audience is, who are we writing for? Well, obviously the agencies; NSF, Agriculture, State Experiment Stations, ARS, Department of the Interior, Department of Commerce, anyone that is interested or could become interested. We look at Congress, at the President, at OMB, these are the audiences. It has to be in terms that they can understand. As we set the report up, we must think how best to present this information. I think we should consider the model of a newspaper article. We put the most important thing first, that is the recommendations. And recommend it in language they can understand, not just our own fraternity, that is one of the big problems we face. We must write so that the audience can understand us. That is number one, the recommendations, like a newspaper article. Then we've got to give our rationale for that recommendation. We'll go back to that in just a minute. Then if we're sensible we'll tell them how the recommendation might be implemented, implementation.

Then we should also consider research priorities and how we look at them. How do we assess or evaluate priorities in research recommendations in terms of rationale. We'll have a little thing distributed on all this tomorrow. If we're to make a research recommendation, we must look upon that in terms of what it will do for production. That is the most important thing I think.

But that is not all, we've gone past the day where we can just go on, as Jonathan Swift said, to make two blades of grass or two ears of corn grow where one grew before. We're beyond the point of just production, there are other things we must consider. We've got to look at nutrition. Do we maintain or do we improve nutrition? Our recommendations ought to deal with that point. In terms of environment. We've gone through an environmental movement. What is the environmental impact, is it good or bad? Hopefully, it will improve total environment. We ought to consider that, we need to consider that. I'm not sure these are in the right order. Perhaps the next one should be resource input. We can no longer give recommendations in terms of increasing production. What kinds of resources will it take must be considered. Are the resources renewable or non-renewable. The cost of the resources. I'm talking about energy, about land, about water, about chemicals and fertilizers. We've got to consider resource input, we've got to consider cost of those resources, we've got to consider the renewability of those resources and the availability of them. That is an important criterion right now for any recommendation.

Then we look at the time frame, everybody wants something yesterday including government agencies. If it is going to take 50 years to get something done, they probably are not interested. If it is five years or two years, this could be an important criteria. So the productive time is important for any recommendation we give. Then we have to consider,I've always said, it has to be economically feasible or it will never be used. We've got to look at cost benefit. Then we could add to that another one, cost effectiveness. They're not the same. Cost benefit is the benefit per cost input. Cost effectiveness is looking at various alternatives to achieve a particular goal. Some of those may be less expensive than others.

Then we can add some others. We ought to look at the importance for this nation as well as less developed countries. We should be concerned about timeliness. Anything that is going to be accepted, has to be timely. We've got to look at the chances for success.

V-1. A. R. CHAMBERLAIN, PRESIDENT, COLORADO STATE UNIVERSITY

I would like, in trying to fulfill the function given to me this morning, to make it very clear that president's are paid to talk but not think. And so, if that becomes very apparent as I convey my remarks to you, please understand this is job definition. I do propose to share with you just a personal layman's perception of the perhaps near term future for agriculture and weather modification and hope that it will simply serve as a whipping boy or girl for you as the case may be, as I don't proport to be an authority in either area.

I would like to make the presumption that there is the capacity on our planet, if we could but solve logistics and financial and operational and social institutional problems, the capacity to feed many, many more people than we probably will be confronted with in this century, so that the problem to me comes around as to whether or not weather modification is going to make a significant dent in this challenge of feeding very large numbers of people. I believe as an amateur and layman, that the answer is that in the aggregate of the planetary need for feeding people, weather modification will be insignificant in the accomplishment of that particular goal. I take that position because of the feeling that no amount of fertiziler and water management, no amount of genetic research, and no amount of weather modification is going to be sufficient to over come, in the magnitudes required, the ability or the lack of ability of nature to deal with droughts and floods and other natural disasters so that the character of famine is going to be with us worsening to a considerable degree. I am quite convinced that we need to do an even better job in fertilizer and water management, genetics, conservation, and weather modification, but that in effect, what you can do with weather modification will be a palliative not a solution. That it will assist in dealing with the world food problem but it will not constitute a solution anymore than these other very, very tremendous technical advances of the last 50 years have been able to do. I suggest that it will probably fall in the realm of being a palliative in part because, again as an outsider to your field, it is my perception that you are a long ways from understanding the basic decay or amplification of coupling in the atmosphere in terms that are communicable to the public policy people and transferable into meaningful law. Now you might as scientists think that you understand at least at the small scale and maybe even in mesoscale some of the amplification and decay mechanisms but I would assert you have not demonstrated the capacity to convey this to legislators or congressmen or others who provide public policy in a way that it can be transformed into operational public policy. So, I then end up concluding that only very limited operational use of weather modification for agriculture is going to be permitted by society.

Even uses permitted and this one bothers me a great deal, even uses permitted will lead to, in this country at least, many more damage suits. The psychology in this country applicable to weather modification is not dissimilar to the psychology back of the behavior in the malpractice suit field dealing with human medicine nor is it all that different from the behavior of people regarding an incredible growth in personal injury suits, much of which is based on the deep pocket theory of law that says, under certain theories of torts, if you have to deal with a jury that the probability is that if there is money there, right or wrong, the aggrieved party is going to get a part of it. So logistically, I suspect you probably can't cover over a tenth of one percent of the agricultural area that is potentially susceptible to weather modification help but you could probably be of real help to say one hundredth of that, to a very small number of specific agriculturalists in extremely high loss crop areas. Your primary contribution may actually be to less than one one thousandth of the significant cropping areas, would have perhaps a high cost benefit performance, but would still make no significant dent in the global food issue. But I would like to convey to you, I think the thing you're still under-estimating is that in our consumer based and legalistically oriented society, at least it is moving in that direction very rapidly, society is not going to permit you to do what you are sure you could do effectively until you do a better job of learning how to communicate into language that can be made into operational public policy law.

My second thought, the layman's technical perspective. It is my feeling that you are approaching the ability to construct a fairly good model of a simple convective cloud, including a hail bearing one, but it is also my perspective that there are going to be numerous surprises and new small scale dynamic effects that will show up that will lead to the conclusion that a lot more research is needed before you yourselves can be confident for even very local weather modification performance on an operational basis. Your own confidence in what you may induce in relation to the natural dynamic variability may be shaken as you actually learn a little bit more about these simple convective situations. I do think, however, it is going to be increasingly essential to proceed with that research and truly find out more of what is going on. In the context of what I said a moment ago, about legalistic-social-consumer constraints, probably growing at an exponential rate, I would suggest that it is important that you figure out ways and means to improve your computer simulation models in order that you can do more of your research in this mode, away from a circumstance where you can anger the public and heighten what is already an anti-research sentiment in our society.

I would like third to come back to reiterate my point about natural variability to exceed your weather modification impact. I really am convinced that weather modification is not going to go very far in helping stabilize the international food production program either as this nation would push it or China or other areas. I am just convinced that your efforts are going to be like the local effects of water management, the local effects of fertilizers, the local effects of seed genetics that even though you try and get beyond the local basis, the limitations of capital formation and these public constraints will preclude you from being more than an iteration in a small way. Now that can be construed positively in that it should give you a basis for arguing that you should be given maximum latitude for the conduct of your research because you obviously are not going to destroy a capability to deal with the world food problem anymore than you are going to achieve a solution. Your research can be relatively benign but certainly fundamentally helpful. But you are going to continue to be overshadowed by droughts and floods over very large areas. So, I would summarize my feelings then on two counts:

1. You will gradually increase your identifiable but small contribution to locally stabilizing some small swings in agricultural production to a very favorable cost benefit ratio in the definable areas of your operation without perhaps being able to demonstrate what actually is induced at distance.

2. That you are going to continue to have lots of intellectual reasons for needing more research, more basic research as well as applied for many, many years to come.

So, I then wrap up by saying as I welcome you to Colorado State University "enjoy your intellectual playhouse."

Dr. Chamberlain's remarks and welcoming as president of Colorado State University were transcribed from the taped proceedings.

V-2 AFTER TWENTY-NINE YEARS - A PROPOSAL

by

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With the 30th anniversary of the discovery of a practical way to modify supercooled clouds[1] less than a year away, it seems that the present time is a logical one to consider our progress in this intriguing field and to assess practical possibilities for the future.

While some of us are inclined to be impatient or frustrated with the progress that has been made over the period of 29 years, there are aspects of the problem that are not easily solved.

Problems Caused by People

The foremost problem that requires a solution has long been referred to as the "people problem." Not only are there individuals or groups who deride and belittle the potential for the modification of clouds and weather, but there seems to be an equal number who feel that far more can be done than is likely to be possible under the most ideal physical conditions.

On the other hand, consider the consternation that would exist if the recent disastrous floods on the Red River of the North could be directly ascribed to rains that developed in a cloud seeding program. Just as the Feather River flood of the mid-fifties and the Rapid City flood of the early seventies had peripheral cloud seeding activities, there are people who are prone to jump at conclusions without much valid data.

The "people problem" will always be with us and should be carefully considered and assessed no matter what program is recommended by this Conference. Proper and intelligent public communication and majority participation are essential ingredients to the elimination or control of this problem.

I should like to leave these aforementioned social problems to the psychologists, lawyers and public relations experts and direct attention to some of the mechanics of the weather modification process. Despite many attempts and much effort to develop better, more effective and less expensive cloud seeding materials, there is as yet no substance that remotely competes with dry ice or silver iodide in ease of use and field effectiveness for producing modification of supercooled clouds. Each of these materials has unique properties and, when properly utilized, are highly complementary.

<u>A Substitute for Silver Iodide</u>

Although there are a number of proposed substitutes such as cupric sulfide, metaldehyde, phloroglucinol, pentaerythritol and other organic substances, I doubt if any of those thus far proposed are likely to displace dry ice and silver or lead iodide for practical utilization for some time to come.

Much effort has been directed toward the utilization of silver iodide, ranging all the way from dispensing it in finely powdered form to melting it in a combustible solid, to burning a silver iodide-sodium iodide dissolved in acetone or other combinations, to using it as a component in pyrotechnic flares, explosive artillery or rockets. I would like to redirect attention to the effective utilization of dry ice (solid carbon dioxide). It is my considered opinion that whenever an aircraft is used for seeding purposes and the plane is capable of flying into or above supercooled clouds, it is a great waste of money and opportunity to not use dry ice fragments for the seeding agent.

It has been my experience in watching and in reading about dry ice seeding operations, that far too much dry ice has been used in most seeding programs. Since dry ice is so cheap relative to any other seeding substance (20¢ to 30¢ per pound at current 1975 prices) as compared to a cost of a hundred times more in the case of silver iodide, the attitude seems to be, "since we can easily afford it, why not use plenty!"

In our Project Cirrus operations, we rarely used more than two pounds of crushed dry ice per mile of flight, and more commonly limited ourselves to one pound per mile. Since the temperature effectiveness of dry ice is superior to silver iodide at all temperatures colder than 0°C, even one pound per mile of the dry ice, if effectively utilized, can produce many more ice embryos than is possible with silver iodide.

I have witnessed the utilization of from 10 to 200 pounds per mile or even per drop! This often defeats its purpose since the extremely cold air generated by the massive drop causes the entire air parcel to pass through the seeded area and thus into the unsuitable air below.

The biggest advantage in the utilization of dry ice for supercooled cloud seeding is the fact that a fragment about a centimeter in cross section will fall a mile before it is completely sublimed. Thus it was our practice during our Project Cirrus studies to crush blocks of dry ice so that the largest pieces were about 1 centimeter diameter, using all the smaller fragments including the finest powder.

The limitation in the use of dry ice is, of course, the fact that it must be put into air that is colder than 0°C, and at least supersaturated with respect to water. Under such conditions a blue fog of ice embryos will stream from a fragment of dry ice with a concentration well in excess of 10^{14} embryos per gram at -16°C.

Thus I strongly urge a revival in the utilization of dry ice in cloud seeding activities. The fact that most of the current weather modification activities in the United States are based on the use of aircraft makes it all the more relevant to do so.

The Removal of Supercooled Clouds

A short time ago I suggested[2] that dry ice be used to bring more sunshine to the earth by removing supercooled stratus clouds. Extensive solid decks of such clouds often greatly reduce the amount of sunshine reaching the earth. While my main proposal was focused on providing more direct sunshine for solar energy collectors, the same feature should be considered for corn, wheat, sorghum and other ground crops that thrive on direct sunshine. A climatological evaluation should be prepared to determine whether such cloud removal would benefit crops and be economical. At the same time, the cloud removal technique could be utilized for training purposes as well as for evaluating proposed substitutes, Parallel legs five to ten miles long could be produced using one pound of crushed dry ice per mile of flight. Substitute materials could then be dispensed parallel to the dry ice reference line. Since the vortices from wing tips and propeller blades also generate ice crystals by homogeneous nucleation, any material to be compared, which requires that the substance is dispensed while flying in the cloud, must have a parallel flight line of the airplane flying in the cloud making a "dry" run.

In this manner one can make visual and photographic evaluations of the effects produced by the seeding materials, thus eliminating the need for statistical studies!

The Production of Clouds to Control Ground Temperature

Under suitable conditions it is just as easy to produce stratus clouds as to remove them. This might be of extreme importance for the alleviation of excessive heating from the unobstructed sun during corn tasseling. We also established this technique during our Project Cirrus exploratory experiments in 1947.

To establish the possibility of producing stratus clouds by seeding, we used a 100 gram pilot balloon filled with helium and carrying a chunk of dry ice suspended in an open mesh bag. As the balloon climbed into the sky, it was watched by theodolite or ordinary binoculars. If, during its ascent, a persistent condensation trail formed, the approximate altitude was noted. Such a trail established the presence of a layer of moist air that was supersaturated with respect to ice. We commonly found such layers existing at altitudes between 15,000 and 25,000 feet.

Such layers could be seeded with dry ice fragments by flying within the top of the moist layer, dropping dry ice fragments into the clear air at the rate of a pound per mile of flight. Quite commonly, when doing so, a condensation trail would form in the engine exhaust plume. Since the air temperature in this portion of the troposphere was never colder than -40°C, the trail remained as a localized water cloud which eventually merged and evaporated onto the ice crystals generated by the dry ice seeding.

As with the removal of a supercooled cloud, the same flight technique should be used in producing a cloud in supersaturated air as would be used for producing holes in a supercooled cloud deck as described in the Project Sunshine paper previously cited.

For a very modest outlay of funds it would be extremely easy to establish the possibilities of cloud production or removal. In view of the multimillion dollar losses that occur when excessive heat prevents the pollination of corn and other crops, such experimental activities should be started without further delay.

The Prevention of Frost by Cloud Production

The presence of a relatively thin cloud of ice crystals produced through the dry ice seeding of air supersaturated with respect to ice might also be useful in controlling nighttime temperatures at times when there is the danger of frost. Just as a daytime cloud will reduce the amount of heating produced by insolation during the daytime, the presence of a similar cloud at night can prevent the radiative cooling of the earth that occurs under a clear sky condition. Thus outearation (outgoing earth radiation), which is the cause of late spring and early fall frosts, can be reduced if an artificial cloud can be formed to prevent this nighttime radiative cooling.

The Educational Value of Cloud Production and Removal

Since it is unlikely that anyone would object to such operations, and since a successful effort at cloud production or removal (depending on circumstances and need) would have dramatic economic and social benefits, such activities would have an educational value that would benefit everyone.

Conclusions

I strongly recommend the development of such activities by the agricultural community as soon as possible. There are so many benefits that would occur, it is unlikely that any serious "people problem" would occur.

The use of dry ice or any other practical means for achieving homogeneous nucleation (liquid nitrogen, carbon dioxide, propane, etc.), completely eliminates any possibility that the seeding materials not utilized could produce distant or long range effects. Since these materials can only generate pure ice embryos, they are completely gone once they move into dry air or temperatures warmer than 0°C.

Thus we come full circle, an experience that often occurs in science and human affairs.

VJS
7/30/75

References

1. Schaefer, V. J., "The Production of Ice Crystals in a Cloud of Supercooled Water Droplets." Science, 104, 2707, pp. 457-459 (1946)

2. Schaefer, V. J., "Project Sunshine." J.Wea.Mod., 7, No.1, p.1 (Apr.1975)

V-3 A National Weather Modification Research Program for Agriculture and Forestry

by

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The members of this NSF sponsored workshop have a challenging task — development of recommendations for a national weather modification program to meet specific needs of agriculture and forestry. In approaching this job an important first step is to examine other previous activities aimed at the development of weather modification programs.

During the last 20 years many other groups have devoted extensive efforts in preparation of detailed plans and recommendations for weather modification. There is now a large bookshelf of program planning documents and reports. These include important reports issued by the President's Advisory Committee on Weather Control, National Science Foundation, National Academy of Sciences, Inter Agency Committee on Atmospheric Sciences, Bureau of Reclamation and many other organizations.

In 1968 the U.S. Department of Agriculture issued a report "Weather Modification for Agriculture and Forestry." The report was prepared by a task force of representatives of USDA agencies, state agricultural experiment stations, universities, meteorlogical organizations, NSF, and the Departments of Interior and Commerce. The taks force report recommends a specific USDA weather modification research program.

The general contents of the 1968 program included:

I. National Goals

1. Food for a growing world population
2. Fiber for the national and world economy

3. Safeguarding Life and Property

4. Protecting Quality of Man's Envrionment, Natural Beauty and Outdoor Recreation

5. Enhancing Water Resources

II. A National Research and Development Program

1. Direct Modification of Weather

2. Biological and Hydrological Consequences of Weather Modification

3. Economic and Social Aspects of Weather Modification

4. Decision Making in Weather Modification

III. Research Resources

1. Research Manpower

2. Scientific Facilities

3. Research Organization

In the report four major areas of research including specific projects for each areas were identified as follows:

1. Direct Modification of Weather

a. Precipitation modification

b. Suppress lightning fire ignition and damage

c. Suppress hail damage

d. Modify local winds, temperature and radiation

2. Biological and Hydrological Consequences of Weather Modifications

a. Assess impacts on biological systems

b. Assess impacts on the physical landscape and hydrological cycle

c. Micro-meteorlogical processes in soil-plant-air layers

d. Monitor biological changes at weather modification sites

e. Develop improved agricultural and forestry husbandry to exploit weather changes

3. Economic and Social Aspects of Weather Modification

a. Assess economic effects

b. Develop knowledge for attacking social and legal problems

4. Decision Making in Weather Modification

a. Develop knowledge for decision making and resolving policy issues.

We can use the 1968 USDA report as one of the references and guides for our present taks. In doing so we should be cognizant of the results produced by the report. Except for the lightning suppression work of the Forest Service there has been little if any implementation by USDA of the recommended programs. Recent USDA policies do not include weather modification as a viable part of the national efforts in agriculture and forestry. Unless we now develop a dynamic, well-founded new program and present it forcefully to USDA and other affected groups (including the general public), there is the likely prospect that another report will gather dust. However, I am confident that our task force fully believes in the opportunities for weather modification to usefully serve agriculture and forestry. The need and the opportunities are too great for us to do anything but adhere to our goals for development and implementation of an excellent program.

V-4. ERIC WALTHER*, GRANTS MANAGER, CHARLES KETTERING FOUNDATION

I think perhaps this conference has been wrongly titled. The term "Agricultural Production" should perhaps be "Food Production", for there are considerable weather sensitive food resources which are not grown on land. In fact, 7 percent of total food is fish and 1/5th of this fish is anchovies. In 1970 this amounted to 12.5 mmt, but because of the disastrous "El Nino" declined in 1972 to 2 mmt. The problem may be compounded by overfishing. For those countries dependent to a large extent on anchovies for protein, an ability to control "El Nino" would be a major breakthrough. Longer term trends in climate are also having an important effect on production of important fish for food. Cooling of the high north latitudes decreases the cod around Greenland. To reverse this trend, a large-scale polar warming would be required. If they work, large-scale schemes such as spreading carbon black on the Arctic ice fields could bring about such warming, but this could also flood currently productive coastal areas. Such ideas need careful evaluation.

As I see it, weather modification can play two major roles to increase terrestrial agricultural production:

1. Reduce the "bad" agricultural weather and so eliminate the low peaks in production.

2. Improve the average agricultural weather and so raise the average yields.

Year-to-year variations in yields are a major disruption to world food systems. If weather modification could ameliorate the "bad" agricultural weather which causes the poor yield years, it would be a major step forward. Such "bad" weather includes:

1. Less than normal rain during the critical periods of the growing season, e.g., July-August 1974 in the corn belt.

2. Too high temperatures during the critical growing season.

3. Drought

4. Floods induced by:
   a. Local brief heavy showers
   b. Several days of heavy rain over a bigger area.

5. Too much rain at planting or harvest time.

6. Hail

7. Severe winter storms that damage winter wheat

8. Too little snow over winter wheat to prevent spring frost damage

The second role for weather modification in agriculture that I can see is in improving average agricultural weather to optimize productivity. Direct effects which might occur are:

1. Increasing precipitation where it is limiting production
2. Decreasing precipitation where flooding is a problem
3. Reducing frost to extend the growing season
4. Increasing the land area usable for agriculture and make currently marginal agricultural climate into good climate.

There are also indirect effects on agriculture by which weather modification could aid production, such as:

1. Reduce energy required for irrigation.
2. Reduce biocide required for insects and plant disease
3. Reduce energy required for tilling (soil moisture).
5. Reduce fertilizer requirement by reducing runoff.

We need as a start to assess the specifics of agriculturally detrimental weather. Is an area which is otherwise excellent for agriculture underproductive because of lack of precipitation? A good start would be to compile maps of detrimental weather, drought, floods, hail, frost, wind. We then need to assess the capabilities of weather modification. Is frost prevention still limited to smudge pots? Can eastern Colorado have windbreaks to reduce wind damage to winter wheat? Can we develop a technology to produce cirrus clouds to reduce maximum temperatures which might adversely affect plant growth?

Agricultural practices also modify the weather. Albedo and surface heat and moisture fluxes are directly affected by agriculture. Timbering changes forest to crop and range lands. Irrigation can change deserts and rangelands to productive crop land. As we have seen in Africa, over grazing can change range lands to desert. Do these changes which affect surface fluxes travel up scale to affect weather? Does increased evapotranspiration from irrigated land lead to enhanced precipitation?

Modification of weather by agricultural practices is just one form of inadvertent weather modification. We have indications that both positive (more rain) and negative (increased hail) affects on agriculture may occur. We may want to modify causes of inadvertent weather modification in order to improve weather for agricutlure. We can anticipate changing quantity and "quality" of industrial emissions and location of emissions. Industrial emissions of aerosols and CO_2 can have significant agricultural implications. Acid rain resulting may significantly affect agriculture anf forestry. Krypton -85 may increase atmospheric conductivity enough to affect rain and thunderstorms.

Finally, it should be remembered that weather modification can be applied either directly or indirectly. It is the direct applications we normally think of, causing more rain or less hail to fall on the crop. It should also be remembered that there is value in increasing precipitation over mountainous areas which will lead to increased runoff and thus increased water available for irrigation. Also, a decrease in stream salinity will occur, making the water of higher quality for agriculture.

V-5

Skywater & Agriculture

By Clement J. Todd

(prepared for the workshop "An Assessment of the Present and Potential Role of Weather Modification in Agricultural Production," supported by NSF/RANN, at Colorado State University July 15-18, 1975)

Division of Atmospheric Water
Resources Management
Bureau of Reclamation
Department of the Interior

July 1975

The Bureau of Reclamation's Skywater research program in precipitation management is concerned primarily with two fields of technology development, both of which are designed to provide much-needed additional clean water for agriculture. They are:

-- The enhancement of growing-season rainfall over agricultural regions and the effect of this added moisture on crops, livestock, water supplies and the natural environment.

-- The orographic augmentation of winter snowpacks for assured spring and summer runoff and the effects of this technology on the environment.

Although mountain runoff provides water for irrigation, the technology being developed in this field will have implications beyond the ranch or farm, extending into power generation, fuel development, municipal water and other uses.

This workshop, however, is concerned with enhanced rainfall as it affects agricultural production.

The Bureau's research in this field has been toward development of an effective, socially acceptable technology for the enhancement of summer showers in the High Plains region, roughly those lands west of the 100th meridan to the foot of the Rocky Mountains. In large part, research in this direction and location has been motivated by a widespread desire among agriculturalists for increased precipitation to improve yields, particularly during dry seasons. The choice also is influenced by many in the scientific and water management community who believe an effective technology is accessible.

Skywater has sought and funded several studies to determine the value of increased growing-season rainfall, and other seasonal precipitation, in the High Plains region. Generally, the research -- much of it involving agro-economic modeling -- has been based on the assumption that the technology could produce a seasonal precipitation increase of 10 percent. Table 1 lists several of these studies.

Research to date indicates the potential value of an applied technology would be great. The studies also reveal that the timing of precipitation is critical for optimum plant production and has a major effect on yields.

It is clear that much more must be learned about crop and range responses to precipitation before the technology is complete.

The question of whether the technology will produce an increase of 10 percent, or more, in seasonal showers is unresolved. The Bureau hopes it will, as do several state governments, many investigators, and others. Some influential individuals, many in state and local governments, believe the technology already has reached an effective level of development. Others are not convinced, and justifiably point to the absence of statistical evidence.

Table 1

Project Skywater Research Studies Related to the

Effects of Weather Modification on High Plains Agriculture

Contractor	Amount	Completion	Description
Illinois State Water Survey	$500,000*	6-30-76	A nonseeding "lead-in" research program including hydrology, economic, ecology, and legal problems
Montana Department of Natural Resources	165,000	6-30-73	A comprehensive study of agricultural, economic, environmental, hydrological, and social effects of additional summer rain in Montana
North Dakota State University	125,000	6-30-74	A comprehensive study of agricultural, economic, environmental, hydrological, and social effects of additional summer rain in North Dakota
South Dakota State University	133,500	6-30-73	A comprehensive study of agricultural, economic, environmental, hydrological, and social effects of additional summer rain in South Dakota
Wyoming, University of	99,966	6-30-73	A comprehensive study of agricultural, economic, environmental, hydrological, and social effects of additional summer rain in Wyoming
Colorado State University	32,089	9-30-73	An investigation of the effects of silver iodide in the digestive systems of goat (rumen) and rabbit (cecum)

*Denotes approximate amount at completion

That the controversy still exists after nearly 30 years of research is indicative of the complexity of the problem.

The Bureau, relying heavily on knowledge gained in this previous work, has initiated a second generation of research designed to resolve the remaining uncertainties. The High Plains Cooperative Program (HIPLEX), a cooperative effort with active support and participation of several concerned state governments, is going into the field this summer. New tools - radar, aircraft, computer facilities - are being developed, tested, and calibrated. Studies in climatology already are underway, along with other base investigations. Seeding tests will begin next year.

One of the initial problems concerning HIPLEX is the organization of concepts of precipitation management into a systemized and quantified set of hypotheses. These will be tested and evaluated in a manner that is credible to the scientist, politician, administrator and the public.

A simplified, generalized statement of hypotheses for augmentation of summer precipitation for the High Plains would read like this:

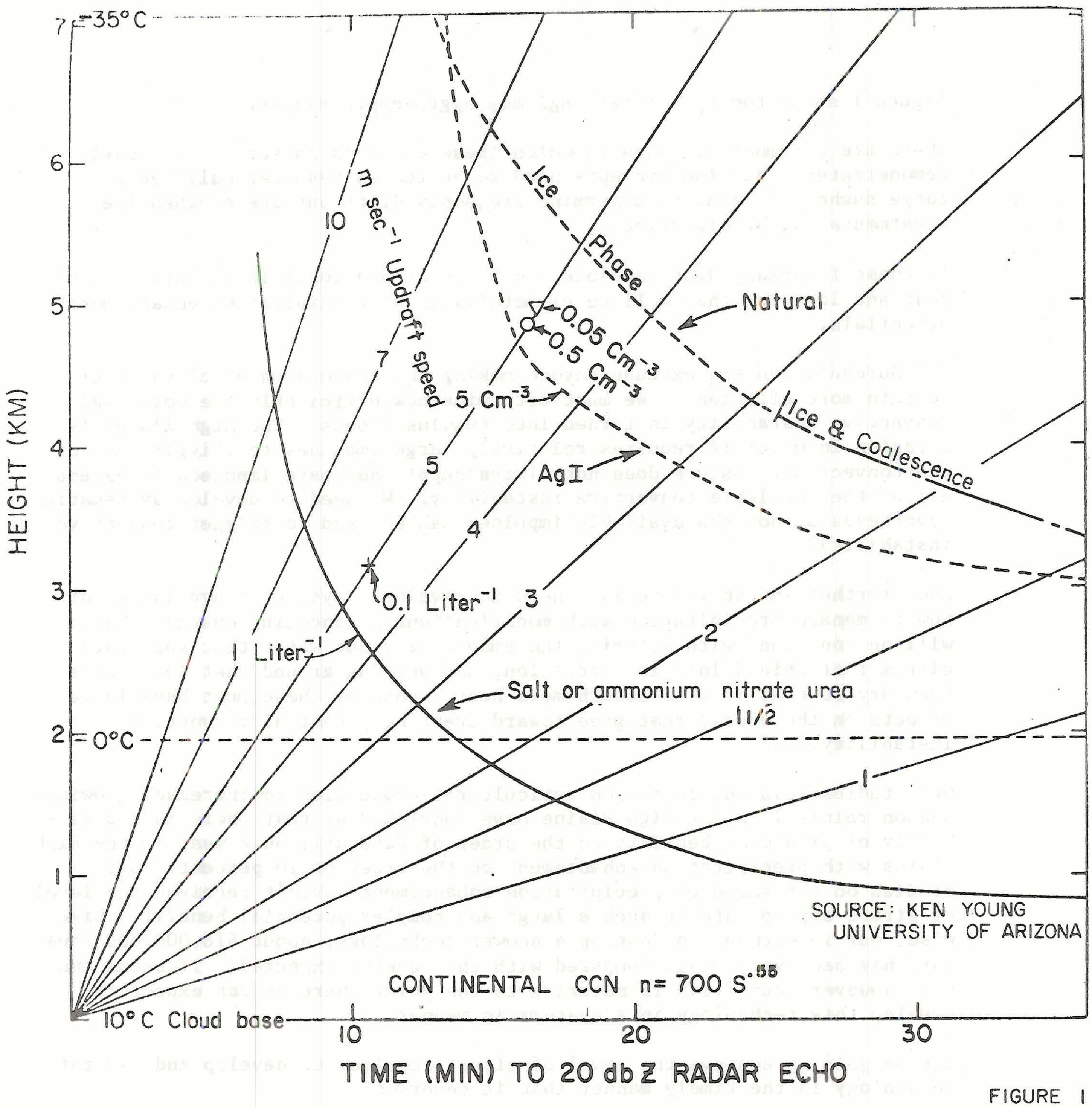
> Summer precipitation in the High Plains comes primarily from convective clouds. It has been estimated from a number of independent studies that these cumulus clouds convert only a small percentage of their cloud water into precipitation that reaches the ground. Most of the convective cloud water is either mixed into dry air aloft and evaporated or is frozen into tiny ice crystals of cirrus anvils. In either case, it is lost to precipitation and soon blows out of the region.

The formation of drops large enough to reach the ground in the High Plains requires about ten million cloud drops be collected into one rain drop. This requires time. A substantial number of the region's cumulus clouds do not permit sufficient time for this process to occur naturally. The cloud bases are quite high and their updrafts are stronger than similar clouds elsewhere. There also are microphysical differences that slow the process more than elsewhere.

Computer models estimate the time required (t_r) for precipitation formation. Model runs have been made assuming (1) that only natural processes are at work, (2) that the clouds had been treated with ice phase nuclei (AgI), and (3) that the clouds had been treated with hygroscopic embrios (ammonium nitrate urea spray or sodium chloride). These t_r factors have been compared with time available (t_a) in High Plains cumulus. It has been found that in a substantial portion of the cloud population:

t_r natural is larger than the t_a
t_r treated is smaller than the t_a

It can be expected that the treatments would capture cloud water for precipitation that would be lost naturally for a substantial portion of the High Plains cumulus.



-35°C
0°C
10° C Cloud base
HEIGHT (KM)
TIME (MIN) TO 20 db Z RADAR ECHO
m sec⁻¹ Updraft speed
10
7
5
4
3
2
1 1/2
1
Ice Phase
Natural
0.05 Cm⁻³
0.5 Cm⁻³
5 Cm⁻³
AgI
Ice & Coalescence
0.1 Liter⁻¹
1 Liter⁻¹
Salt or ammonium nitrate urea
SOURCE: KEN YOUNG
UNIVERSITY OF ARIZONA
CONTINENTAL CCN n= 700 S.56

FIGURE 1

Figure 1 shows the t_r natural, AgI and hygroscopic ranges.

There are a number of cases in which these concepts appear to be clearly demonstrated. But the concepts need to be tested systematically on a large number of cases to determine frequency distributions of when the treatments can be effective.

If these frequency distributions can be developed conditional upon time of year and location they will be climatologies of precipitation enhancement potentials.

The Bureau's concern extends beyond making the conversion of cloud water to rain more efficient. We must determine how efficiently the potential convective instability is turned into cumulus clouds. The High Plains is a region in which it requires relatively large impulses to trigger much of the convection. Nature does not always supply adequate impulses to expend all of the available convective instability. We need to develop systematic hypotheses of how the available impulses can be used to trigger convective instability.

Even further in the future is a need to develop a system of hypotheses of how to manage precipitation with modifications of incoming energy. These will be concerned with altering the amount of cloud water that goes into cirrus that shield incoming radiation, and wetting ground that would have been dry so that it will absorb more heat. Both of these must have large affects on the energy that goes toward creating potential convective instability.

Our studies relating increased agricultural production to increased growing-season rainfall in the High Plains have convinced us that there is a possibility of producing benefits on the order of $250 million a year in the High Plains with precipitation enhancement on the order of 10 percent. Our studies on the value of precipitation enhancement haven't received the level of effort appropriate to such a large and complex potential benefit. Likewise, our investment to develop a shower technology, about $18,000,000 thus far, has been very small compared with the benefit expected. It seems that now, however, our field is maturing to the point where we can expect to develop this technology in a systematic manner.

Let us join to achieve the level of effort required to develop and use this technology in the timely manner that it deserves.

ADDITIONAL COMMENTS
BY

Clement J. Todd
Division of Atmospheric Water Resources Management
Bureau of Reclamation

(In addition to report given at Workshop on Assessment of the Present and Potential Role of Weather Modification in Agricultural Production)

I. Funding for Research in Development of Technology for Precipitation Management

There are a large number of critical problems that we are now ready to explore, but are limited due to lack of funding. There are sufficient problems to make very good use of twice the present funding rate. There are enough highly qualified people with equipment and facilities who are anxious to work in precipitation management and use the funds wisely.

In the future, the field will shift emphasis from managing the moisture budget cloud by cloud, to managing the moisture and energy budget over an increasingly wide area. To do this will require experimentation and analysis on an expanding scale.

If development of the technology is to proceed, funding should be doubled at the rate of once every 3 or 4 years for the next 12 years or so. The rate at which additional funds can be put to use can be evaluated as research progresses.

II. Cost of Operational Projects

At present, some operational projects are run for as little as \$0.03 to \$0.05 per acre per season. I believe that this is so little that it does not support a sound project nor cover the costs that such projects will be required to carry in a few years. If these projects are producing a 10 percent increase in rain, the benefit-to-cost ratio is on the order of 20/1 or even greater. A reason why costs are kept so low may be a lack of credibility. If credibility existed, the projects might be upgraded to include:

1. More pilots and meteorologists
2. More recording radars, soundings, and analyses for evaluation
3. Use of hygroscopic treatment
4. Reimbursement for possible disbenefits
5. Public information
6. Legal aspects
7. Economic and social studies

It seems to me that as the field matures, the costs will rise to at least 20 percent of the benefits. I think that for this report to be responsible, it should prepare the reader to expect much more sophisticated and expensive projects.

V-6

Weather Modification in Minnesota

by

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July 16, 1975

I. History

Weather modification (cloud seeding) in Minnesota was first attempted in 1959. And according to the two individuals most directly involved, Mr. Vince Stegner of Ortonville and Mr. Gerald Michealson of Dawson, other years probably include 1960, 1961, 1968 and 1970. The seeding in all years was performed by the Water Resources Development Corporation, Palm Springs, California. The seeding activity has centered around Big Stone and Lac Qui Parle Counties, both of which adjoin South Dakota. In later years, the area was expanded to include at least three more Minnesota counties, Chippewa, Stevens, and Yellow Medicine, as well as Grant and Roberts Counties in South Dakota.

Financial support of the cloud seeding was by voluntary contributions. In the first year, with only two counties involved and little time available for organization, the money came from donations of a few businesses and farmers who were asked to contribute about $5 per quarter section. There was not enough time that first year to collect from absentee landlords. In later years, the means of obtaining funds was better organized. One year the major source was the Chambers of Commerce of a number of the towns and in another year, county funds were supplied by the commissioners in perhaps three of the counties--Lac Qui Parle and Chippewa in Minnesota and Grant County in South Dakota.

In any case the per acre fee for cloud seeding has amounted to about one cent per acre. If seeding had been done in 1975, the acre rate would have been appreciable higher at about five cents per acre.

The largest area to be contracted for was in 1970 and equaled about 2.5 million acres.

Efforts were made in 1975 to establish a cloud seeding project, but they were without success. There were probably two reasons for this. The group in southwestern Minnesota that had been instrumental in raising funds in previous years may have placed most of their efforts and hopes in legislative action this year. But the legislature failed to pass any weather modification bills. In addition, the above normal rains of April and again in June may have dampened any remaining enthusiasm for cloud seeding. Finally, I believe that special note should be made of the fact that the Water Resources Development Corporation advised the southwestern Minnesota group last winter that 1975 would not be a drought year. Rather they were advised to prepare for serious droughts in 1976 and 1977.

The Water Resources Development Corporation employs only ground generators. Orginally, the AgI source was from the ground based generators in which AgI impregnated coke was burned. Newer generators are now used and are electric (220 V.) with AgI impregnated electrodes. The generators are usually located at gas stations or motels so that the generators can be started or turned off any time during the day or night as advised by the Water Resources Development Corporation. The operators are paid $1 per hour for their services by the corporation.

II. Legislation

The earliest weather modification legislation occurred in 1969. This legislation (Chapter 771) allowed nine Minnesota counties to spend up to $5,000 per year for weather modification or weather control. The nine counties are Big Stone, Chippewa, Grant, Lac Qui Parle, Pope, Stevens, Swift, Traverse and Yellow Medicine.

The first piece of legislation concerning weather modification presented to the 1974-1975 Minnesota legislature would have permitted Lincoln County in southwestern Minnesota to spend up to $15,000 per year on modification activities. The nine previously listed western Minnesota counties also have this power but are limited to $5,000. This bill was withdrawn by the author rather than having it defeated. Strenuous objection to this bill was raised by at least one legislator who represented a downwind constituency. Three amendments to the bill were presented, which may be of some interest. The first one would have required a statement from the Creator authorizing mere mortals to engage in rainmaking. The second amendment would have authorized surrounding counties to obtain thier own air force with which to shoot down the weather modification flights. The first amendment was defeated by 31-19, and the second lost by 32-7. The final amendment was successful and forced withdrawal of the bill so it would not be defeated but remain on the calendar until some future date. This amendment required approval of the surrounding counties, and further that Lincoln County was to carry liability insurance.

A second weather modification bill (House File 385 and Senate File 461) was presented to the legislature in the 1974-1975 session. Hearings were held, and at one time it seemed the bill would be passed. However, it too was withdrawn for further consideration at a later date. Apparently, the sponsors believed that other pieces of legislation had higher political and financial priority. There was no discernible organized opposition so this bill may well be successful in the next session of the Minnesota legislature.

Because this bill will probably be presented again, the details may be of some interest. The bill calls for a $200,000 appropriation for weather modification and the licensing of the weather modification operators. The supervision of weather modification activities is placed with the Commissioner of Agriculture.

The application fee is $35 and a $100 license is required. The license is to be issued only to applicants "who demonstrate to the satisfaction of the commissioner reasonably sufficient competence in the field of meteorology...". The annual renewal of the license requires a fee of $100.

An interesting feature of the bill is the proof of financial responsibility requirement which reads as follows: "The applicant shall demonstrate... that he has the ability to respond in damages for liability which might reasonably result from the operation for which the permit is sought." This is the extent to which the bill deals with the liability of the licensee. There is no indication of what constitutes a reasonable ability to pay for damages.

The bill calls for an appropriation of $200,000 for the biennium commencing July 1, 1975. These funds were for the commissioner who was to "carry on operations and research and experimentation related to weather modification on a statewide basis by staff members, or by contract with approved cloud seeding organizations or in cooperation with other agencies as provided by law".

III. Public Education

The Countryside Council, an organization of 17 southwestern Minnesota counties formed as a result of a Kellogg Foundation grant, is preparing a booklet on weather modification for the edification of the general public and local high school students.

The Agricultural Extension Service of the University of Minnesota is also planning to publish Fact Sheets describing weather modification principles, potential value, possible hazards and the problems of evaluation.

IV. Research

There is no weather modification research *per se* in the state of Minnesota. Representatives of the Bureau of Reclamation have met with Mr. Kuehnast (the Minnesota state climatologist) and me on two occasions. At the first meeting, representatives of number of different university departments and state agencies who would have an interest in the topic were invited. The Bureau representatives indicated that research proposals would be welcomed. None have been submitted as far as I know.

Mr. Kuehnast and I have developed a relatively dense state-wide network of precipitation gages. There is the equivalent of one gage every 42 square miles for the 84,000 square miles of the state. Of course, the distribution is not uniform and the greatest density is in the agricultural areas of the west and the southern one-third of the state. With seeding taking place in both North Dakota and South Dakota the network could be useful in evaluation of the downwind effect.

It should be pointed out that results from our "fine-mesh" precipitation gage network in the Twin City metropolitan area indicate that relatively minor topographic features can be effective modifiers of precipitation under certain wind conditions. Because these topographic features are not operative under all precipitation conditions, they can be easily overlooked and the results incorrectly ascribed to an urban influence, for example. This result plus the extreme variability of precipitation make it appear that the evaluation of cloud seeding is a most difficult task in which a five year study period would be an overly optimistic minimum.

Of special interest is a thesis study in the Department of Soil Science to determine the influence of weather upon crops in Minnesota. The application to cloud seeding is that this study can be used to measure the effect of water, either the lack of it or its addition, on various crops at different times during the growing season. This is a more detailed study than others of a similar nature in that the state yields are not lumped together as one unit. Rather the state is considered as composed of different climatic and agricultural regions. This is particularly important as Minnesota is a "border" state in several respects. First, it is on the northern margin or border of the corn belt and temperature is usually the most important climatic element. Second, Minnesota is on the border of the subhumid to semiarid areas and in the western part of the state water is usually the all important climatic element. These two features make Minnesota an interesting and relatively unique area to study, and the results of such a study can be most valuable.

It is believed that this study will be of aid in determining the timing of weather modification operations. It can also be used to show the potential advantages and potential hazards of such operations.

I am endebted to the following individuals for providing me with information for this paper. I remain, however, responsible for all statements made.

I. History

Orville Gunderson, Area Soil Agent, Morris, MN.

Gerald Michealson, Businessman, Dawson, MN.

Vince Stegner, Businessman, Ortonville, MN.

II. Legislation

Randall D. Young, Administrative Assistant, Department of Agriculture, State of Minnesota, St. Paul, MN.

Assessing The Costs and Returns of Weather Modification

*Willis Peterson

Costs

There are two major components in the overall cost of weather modification: 1. the cost of the research which produces the knowledge that in turn enables man to modify the weather, and 2. the cost of the actual weather modification procedures, e.g. cloud seeding. In regard to the first component, we should expect a considerable lag between the research expenditure and the time the knowledge is forthcoming. In agricultural research, there is some evidence to suggest that the lag between research and the start of its payoff is in the neighborhood of 5 to 8 years. As expected, a longer lag tends to be associated with basic research than with more applied or developmental efforts. Because of this time lag, it is necessary to accumulate the research costs forward in time (as opposed to just summing these costs) using the formula $\sum_{i=1}^{n} C_i\ (1+r)^i$ where "C_i" is research costs in year "i", and "r" is the interest rate. The "i" is the year in which the expenditure is made. For example, "i" would be 1 for research done one year ago, 2 for two years ago, etc. The interest rate should be the rate of return (before taxes) the research funds could earn in their next best alternative use in either the public or private sectors of the economy.

Returns

The returns to weather modification can be measured by the value of additional output that society receives as the result of more "favorable" weather. In agriculture this would be the value of additional agricultural output. Economists generally refer to this value as "consumer surplus". It is a return to consumers and should not be confused with additional revenue to farmers. Indeed, if the demand for agricultural products is such that market price declines more than in proportion to the increase in output, total revenue received by farmers as a group will decline. This phenomenon is more likely to occur if all farmers in the country are affected by a particular innovation. If a relatively small proportion of all farmers are affected by an innovation, total revenue of these farmers likely will increase. Of course, even where total revenue to all farmers as a group declines, it is to the advantage of each individual farmer to adopt or utilize the new technology because by doing so each farmer's profits are larger than they would otherwise be.

The value of consumer surplus stemming from a new innovation is measured by the area between the supply curve of agricultural products without the new technology and the supply with the improved technology bounded on the right by the demand curve. The consumer surplus is the shaded area in Figure 1.[1/]

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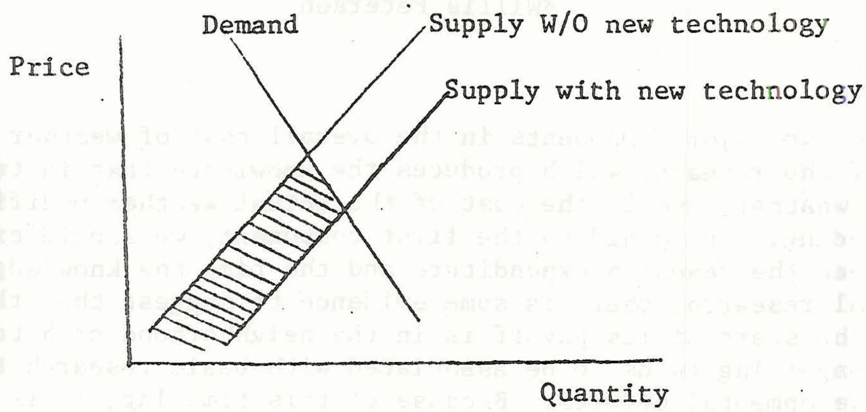
1/ For additional discussion on the measurement of the returns to research see Griliches 1958, Peterson 1967, 1971, and 1974, and Schultz 1953.

Figure 1. Consumer Surplus Resulting From New Technology



Because the returns to new technology such as weather modification are forthcoming over a long period of time, it is necessary to assess future as well as present returns. However, future returns should be "discounted" back to the present, rather than simply adding them up using the formula $\sum_{i=1}^{n} R_i/(1+r)^i$ where R_i is the returns in year "i" and the r is the same interest rate mentioned above. The "i" would be 1 for returns forthcoming one year in the future, 2 for two years, etc.

If one is mainly interested in evaluating the social profitability of weather modification research, the cost of the weather modification procedures, the second component mentioned above, should be subtracted from the returns (value of consumer surplus) to obtain an annual net return to this research.

Social Profitability

In evaluating the profitability of an investment, it is common to accumulate the costs up to the point where the investment begins to pay off using the cost accumulation formula presented above. Similarly the future returns generally are discounted back to the same point in time, using the discounting formula presented earlier. The investment is deemed socially profitable if the sum of the discounted returns is at least equal to but preferably larger than the sum of the accumulated costs. Frequently the discounted returns are divided by the accumulated costs to obtain a benefit/cost ratio. An investment is worthwhile if its benefit/cost ratio is at least equal to but preferably greater than one. Alternatively one can compute an internal rate of return to the investment. The internal rate of return is that interest rate (the r in the above formulas) that makes the accumulated costs equal to the discounted returns. An investment is socially profitable if its internal rate of return is at least equal to the rate of return (before taxes) on the next best alternative use of these funds.

Expected Versus Actual Costs and Returns

In weather modification research, as in any other investment, one can never be certain of the returns until after the investment has been made and has yielded its payoff. In many cases, the actual costs are never known with certainty either. Before a decision is made to undertake an investment it is important to estimate as closely as possible the expected costs and returns of that investment. Admittedly these estimates are based on limited and imperfect information but if liberal estimates of costs and conservative estimates of the returns are made, large mistakes can be avoided. It is important also that once an investment has been made and yielded a return, an assessment is made of actual costs and returns. This is particularly true if similar investments can be made in the future, or in other areas or countries.

Average Versus Marginal Costs and Returns

In many kinds of investment, including that of weather modification research, it is possible to assess its profitability at alternative stages. On the one hand it is possible to estimate the overall costs and returns to the entire investment, either expected or actual. The resulting internal rate of return in this case applies to the average dollar invested in the entire project. On the other hand, it is possible, and common, to estimate the costs and returns to additional investment in the project under consideration. In this case we are computing the rate of return on the additional dollars invested. Economists call this a marginal rate of return.

In making decisions to invest or not to invest more money in a project, the relevant criterion is the marginal rate of return to this investment. The rate of return to past investment (average or marginal) should not influence future investment decisions, unless of course, there is reason to believe the future rate of return will be the same as the past rate. In matters of economics as in many other activities, we should let bygones be bygones except to the extent we can learn from past experience.

Externalities

In recent years society has become more concerned with the "spillover" or external effects of investment. This problem would seem to be particularly important for weather modification. In evaluating the returns to weather modification from the standpoint of society, it would be necessary to subtract any losses that one part of the country might experience from the benefits enjoyed elsewhere. For example, if cloud seeding in one state reduced rainfall in another, the resulting losses would have to be subtracted from the measured returns. Of course, where losses are significant and can be anticipated in advance, legal action by the state to be adversly affected may prevent the investment in the first place.

Similar to other new technology, weather modification also may have an impact (favorable or unfavorable) on certain industries. For example, more adequate rainfall may reduce the demand for irrigation wells and pumps. As a rule, such effects have not been considered serious enough to prevent investment in research and new technology or to require an adjustment to the measured benefits because the released resources are available for other uses.

References

Griliches, Zvi, "Research Costs and Social Returns: Hybrid Corn and Related Innovations", Journal of Political Economy, October 1958.

Peterson, Willis, Principles of Economics: Micro, Revised Edition, Chapter 12, "The Economics of Science and Technology," Richard D. Irwin, Inc., Homewood, Illinois, 1974.

________,"Return to Poultry Research in the United States," Journal of Farm Economics, August 1967.

________, "The Returns to Investment in Agricultural Research in the United States," in Walter L. Fishel, (ed.) Resource Allocation in Agricultural Research, Univ. of Minn. Press, Minneapolis, Minnesota, 1971.

Schultz, T. W., Economic Organization of Agriculture, McGraw-Hill, New York, 1953, pp. 99-124.

V-8. CHARLES ANDERSON*, PROFESSOR OF METEOROLOGY, UNIVERSITY OF WISCONSIN

I don't have any prepared remarks which means that I didn't come here with my mind already made up to what was going to happen. Listening to the conversations this morning reminds me of an installation we have on campus at the University of Wisconsin. It is a big square building that doesn't have any windows, it looks something like a fortress and it is called a Biotron. Inside this building there are various rooms in which one can completely vary various elements that have to do with the growth of various plants. So one can control the light level, one can control the spectrum of light that is falling on the plant, one can control the temperature in the room, temperature cycles that the room undergoes, one can control the humidity, one can control the moisture, one can control the airflow through the room, one can control the hydrometeors that fall on the plant, one can control the pollutants that the plants are exposed to, and one can control the quality of these things, whether it is water quality or etc. So it seems to me that the agriculturalists are handing the weather modifiers a shopping list or something like that, we want you people to do this for us. I don't know what the weather modifiers have told the agriculturists in the past but I would say that we cannot make rain on demand, we cannot stop rain on demand, we cannot make hail on demand, and I don't think we can stop hail on demand. We cannot make droughts on demand and I don't think we can stop droughts on demand. We can't make floods on demand and I don't think we can stop floods on demand. So I think out of these next few hours together, we have got to come to some kind of a common understanding of what we can do for one another. I came with the expectation of appreciating the problems that the agriculturists face and I hope that in our deliberations that you can appreciate what we are prepared to offer. Perhaps out of that sort of dialogue we will reach a much better understanding of how we can assist one another. Certainly we won't be able to provide you with biotron, that is for sure.

It seems to me -- and I discussed this with my roommate last night -- I think one wonderful thing the conference did, maybe it was just accidental in my case, but they just put people together alphabetically. I don't know how -- but I got to room with an agriculturist and so we got to talking and comparing things and we kicked around ideas and it seems to me in the world of weather modification, particularly in the area of water, and water demands might have a role to play not so much in trying to ameliorate crises situations -- we had a drought and we need rain or we have a flood and we want to stop rain, but it is perhaps trying to work within the hydrologic cycle to help those differing elements in the hydrologic cycle, the storage capacity so to speak, so that you can have a more reliable flow or distribution of water substance when needed. So, I think it would be fatuous in the weather modification community to say yes, we'll be able to give you an inch of rain when the corn is getting ready to go into the tasseling stage. Maybe we can say yes, we can perhaps enhance precipitation when it is precipitating maybe several months before that time or half a year before that time to increase the storage capacity or whatever you are going to use whether underground or subsurface water, irrigation water, etc. Maybe we can do that so that that will be available at the time that you need it. But if we are going to talk in terms of real sizable goals, I think we have to come back to these actual facts. I am hopeful that out of the deliberation of the next couple of days, that I come away with what I consider reliable knowledge about the agricultural needs. I am going to do my best from my experience to try to temper your enthusiasm about what weather modification can do for your problem.

V-9. EARL G. DROESSLER, RESEARCH ADMINISTRATION, NORTH CAROLINA STATE UNIVERSITY

I understood from our co-chairmen, Lew Grant and Sylvan Wittwer, that our workshop purpose was an attempt to chart in bold strokes the future of weather modification activities for the benefit of agriculture. Under this theme I wish to offer one point for the conference to consider, and I will do this by asking and answering three questions.

My first question is, in the years ahead will serious drought conditions return to the major graineries of the United States? My answer is a firm YES. I say yes after listening to our best climatologists, such as Murray Mitchell and Reid Bryson, who say simply that cycles of drought are natural events in the steady march of the climate.

My second question is, if the future drought conditions persist, will the farmers and the people demand assistance from their governments to combat the drought? Again I say, yes, because of our recent experience with drought in Texas, Oklahoma and Florida. The people, who were mainly farmers, went to their governors and the governors went to Washington to seek forces to fight the drought. The Bureau of Reclamation, the military, and NOAA all became involved. Emergency funds were made available for the White House, cloud seeding operations began, and NOAA did a nice job in coordinating the program under the emergency conditions.

My third question is this: Where in the federal government is the responsibility to respond and provide leadership for drought amelioration actions? Who does the planning? Who carries on? Who nurtures and expands on the experiences we gain? My answer to this more complex question is "no one has the responsibility." There is a gap in our government structure, and we ought to do something about it. But what?

On another occasion, and largely to stimulate discussion and hopefully action, I wrote the following:

"There is one action we should push, and push hard: Senator Bellman's Bill S-3313 authorizing the Secretary of Agriculture to carry out an emergency drought assistance program in any state in which livestock or crops are threatened by drought. On the basis of a proposal from the drought-stricken state, the Secretary would make matching federal funds available to a state organization to initiate weather modification operations to combat the drought conditions. It is essential that this authority be vested in the Department of Agriculture because that is where the responsibility rests for our national efforts on livestock and crops. Also it is about time for the Department of Agriculture to become more visable as a major support agency for weather modification research and technology. After all, hail and lightning suppression, rain and snowfall management, severe storm amelioration, etc., are all critical to our agricultural enterprise -- and it has been too long now that the Department of Agriculture was looking the other way when leadership for weather modification programs was called for. I am going to add one additional idea and suggest that the Congress also authorize the Secretary of Agriculture to establish a National Institute for Weather Management for Agricultural Purposes. With an ongoing Institute, the Department of Agriculture would have the expertise and the supplies and equipment to assist the states in the design and in carrying out weather modification field operations under drought conditions. We also lack some know-how and experience in mounting any long-term, frontal attack to relieve drought situations. I see the Department of Agriculture getting on with this and related work, if the Congress will pass a favorable law and appropriate the required budget."

I hope that this workshop will get behind this suggestion and make it one of its strong recommendations. I am very optimistic that meteorologists and agriculturists working together can make great things happen.

V-10

POSSIBLE AGRICULTURAL GAINS FROM WEATHER MODIFICATION BY CARBON DUST ABSROPTION OF SOLAR ENERGY

by

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85 percent. As pictorially shown on the left portion of Fig. 1, the largest portion of incoming solar energy is absorbed by the oceans. Most of this energy subsequently goes into evaporation. Because this evaporation energy transport from the ocean is not directly dependent on solar radiation, but goes on during both the day and night, the oceanic boundary layer does not experience a large daily heating cycle as is common over land.

If a significant portion of the incoming solar energy over the oceans could be absorbed in the atmospheric boundary layer over a meso-scale area during the daylight hours, an artificial stimulation of meso-scale convection would likely result. This might be accomplished by aerosol interception of solar radiation as shown on the right side of Fig. 1. Figure 2 compares the extra boundary layer short wave heating which is possible in 10 hours due to 15 percent extra absorption of incident solar radiation with the usual 10 hour net long and short wave radiation of the tropical troposphere as determined by Cox and Suomi (1969).

Carbon black is formed by the controlled incomplete combustion of fossil fuels according to a variety of processes. If put out in sizes less than a few microns, it has negligible fall velocity. Most carbon blacks can be produced in quantity for about \$.05 to \$.10 per kg. The high radiative absorptivity and low heat capacity (about .125 cal/g^{o}C) of carbon dust make it an ideal agent for interception of solar radiation and transfer of this heat to the surrounding air molecules by conduction. Being hydrophobic, carbon dust does not readily absorb water vapor. If put out in small sizes it will not act as a condensation nucleus. Particles of 0.1 micron radius maximize the solar absorption per unit mass but this size is not critical. Solar absorption to weight is not greatly altered by variations in size from .01μ to 0.20μ radius. One kilogram

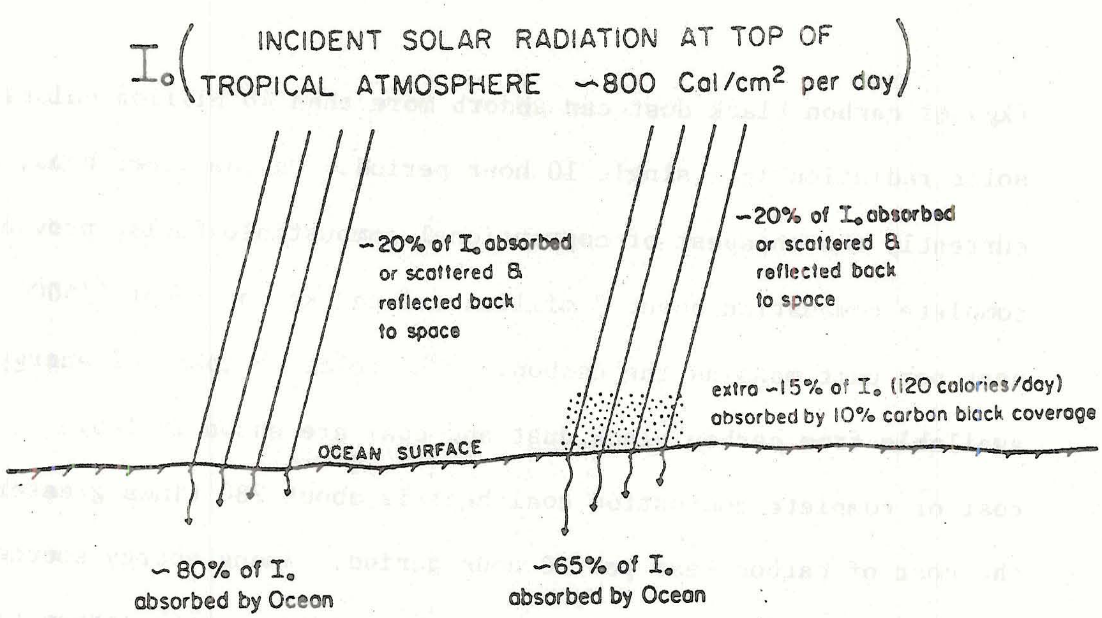

Fig. 1. Contrast of clear air tropical condition with normal solar absorption by atomosphere-ocean (on left) with extra solar absorption with 10% aerosol coverage in the boundary layer (on the right).

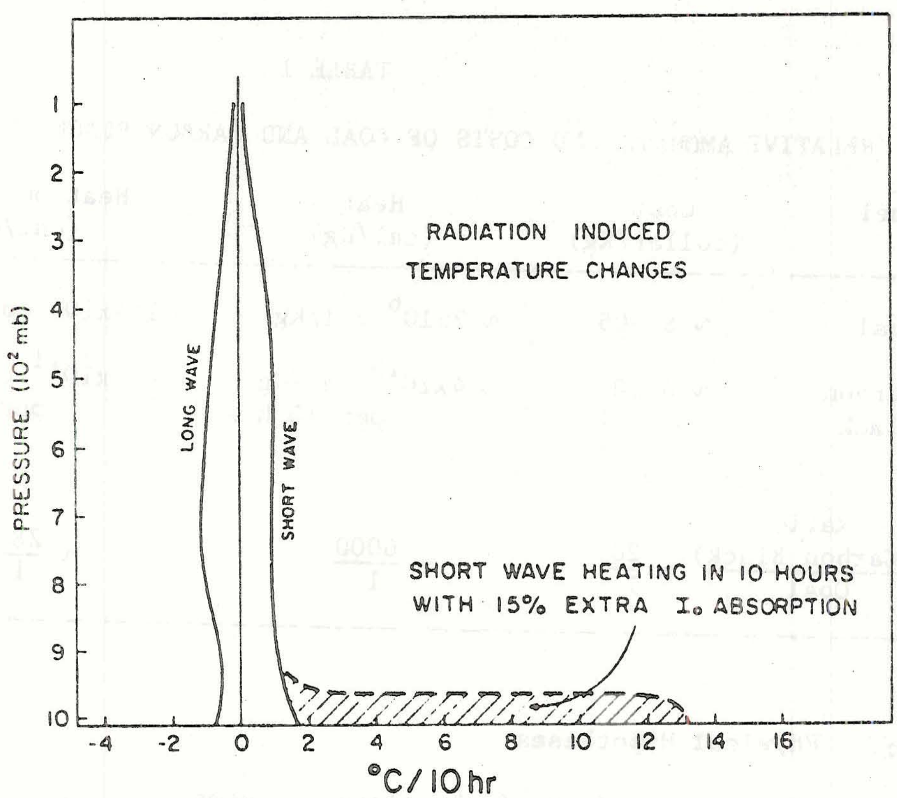

Fig. 2. Comparison of 10 hr heating-cooling rates due to long and short wave radiation in clear regions with the extra boundary layer induced heating (shaded area) which is possible in 10 hours from 15% artificial solar absorption.

(kg) of carbon black dust can absorb more than 40 billion calories of solar radiation in a single 10 hour period. On the other hand, coal, currently the cheapest of conventional combustible fuels, provides on complete combustion about 7 million cal per kg, or about 1/6000 as much heat per unit mass as the carbon. The relative costs of energy available from carbon black dust and coal are shown in Table 1. The cost of complete combustion coal heat is about 280 times greater than the cost of carbon heat per 10 hour period. Among energy sources normally used by man only nuclear energy compares with carbon black as a source of accumulation of energy per unit mass, and no known substance compares as a source of heat per unit cost.

TABLE 1

RELATIVE AMOUNTS AND COSTS OF COAL AND CARBON BLACK DUST ENERGY

Fuel	Cost (dollar/Kg)	Heat (cal/Kg)	Heat per Unit Cost (cal/dollars)
Coal	∿ $.005	∿ 7×10^6 cal/Kg	∿ 1.4×10^9 cal/dollar
Carbon Black	∿ $.10	∿ 4×10^{10} cal/Kg per 10 hrs.	∿ 4.0×10^{11} cal/dollar per 10 hrs.
Ratio $\frac{\text{(Carbon Black)}}{\text{Coal}}$	∿ $\frac{20}{1}$	∿ $\frac{6000}{1}$	∿ $\frac{280}{1}$

c. Physical Hypotheses

The energy budget of the globe dictates that the average global precipitation be about a meter per year. The larger portion of this precipitation falls over the oceans and is of no benefit to man. If man could better organize meso-scale convection over land, a small percentage increase of global land precipitation might result. This could have a sizable beneficial economic impact. The proper tapping of solar energy with carbon dust might give man control of an energy source sufficiently large to allow him to objectively contemplate such possibilities.

On a less ambitious scale it is hypothesized that beneficial meso-scale weather modification may be possible in the coming decade or two by solar absorption of carbon dust in the following situations:

1) rainfall enhancement along tropical and sub-tropical coastlines,
2) cirrus cloud generation,
3) cumulonimbus enhancement over selective land regions in need of precipitation,
4) alteration of extra-tropical cyclones,
5) accelerating snowmelt in agricultural areas,
6) inhibit northern hemisphere cooling trend.

These are a few of the potential applications to which the interception of solar energy on a meso-scale might be put to use by man. There are likely many other atmospheric situations in which man could benefit from application of a heat source of the magnitude to be discussed.

The most likely location for carbon dispersal is over the oceans where the planetary boundary layer does not experience a diurnal temperature cycle and where the stimulation of extra evaporation is possible.

Extra evaporation. The direct heating of air by carbon absorption is but one of two influences which can occur. If accomplished over water bodies, the enhanced solar heating of the air should also stimulate an increase in evaporation. The increased warming of the air will stimulate extra vertical mixing and downward penetration of upper level dryer air to the ocean surface. This dryer air will increase the water vapor pressure difference between the ocean and the air (or $q_s - q$, where q_s represents saturated specific humidity equivalent to the ocean surface temperature and q the value of air specific humidity just above the ocean) and likely lead to increased evaporation rates. Evaporation rates may perhaps be increased by double or more their normal values. This evaporation influence can also continue for many hours after the heating has taken place. The energy for this increased evaporation, however, will come largely from the ocean and not the air. Thus, it may be possible for the carbon dust solar heating to locally extract energy from the ocean that would not naturally occur. The potential buoyancy of the low levels will be enhanced by the extra water vapor content.

Method of dispersion. It appears that it will be possible to manufacture small ∿ 0.1 micron (μ) size carbon particles directly from liquid petroleum products (i.e. hydrocarbons) on aircraft or from ship or land surface sites. The paper by Gray et al (1974) discusses how it is possible to obtain about 50% mass yield of small carbon particles directly from the burning of liquid hydrocarbons. Thus, carbon particles can be generated in the desired size range and dispersed without storing. This prevents handling and clumping problems. Feasibility studies are in progress to determine the best methods of manufacture. It is highly desirable that the carbon particles be manufactured at individual dispersion sites. Liquid petroleum can be much more easily handled and dispersed than can solid carbon dust which is purchased from the factory.

d. Discussion of specific physical hypotheses

Rainfall enhancement along tropical and sub-tropical coastlines.

Precipitation enhancement from weather system genesis or intensification upwind from coastlines with on-shore flow is believed to be a very likely possibility. There are many coastal and adjacent inland regions in the tropics and sub-tropics which need additional precipitation and which have on-shore flow. If tropospheric vertical wind shears are not too large, it is very likely that meso-scale weather system genesis or enhancement is possible.

It must be emphasized that we are discussing meso-scale heat sources of the approximate magnitude shown in Fig. 3 and the resulting meso-scale convective patterns which are induced. We are not discussing the direct stimulation of individual cumulus elements. The individual cumulus elements will result as a consequence of the extra meso-scale low level mass and water vapor convergence. Most previous weather modification schemes have dealt only with the alteration of already existing cumulus.

It is envisaged that an artificial meso-scale heat source would organize or enhance a meso-scale area of cumulus convection. A sizable amount of extra low level mass and water vapor convergence should occur. If enough extra convection occurs, and, if tropospheric vertical wind shears are not too large, this extra cumulus heating is likely to feed-back to the meso-system and keep it going or intensify it. Maintenance and growth can occur after the original heat source has dissipated. Figure 4 shows how a weak meso-scale cloud cluster system might be generated upwind from a tropical coastline.

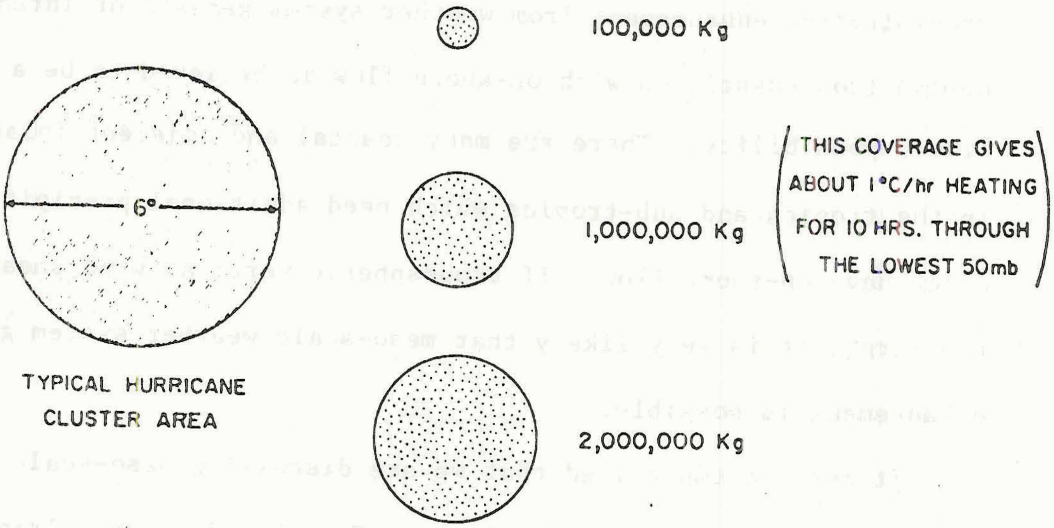

Fig. 3. Comparison of typical hurricane cluster area (6^{o} latitude diameter) with the area (dotted) of 10 percent carbon black coverage which is possible with various amounts of carbon black dust. Estimating the cost of carbon dust to be ~\$0.10 per kg, these three area coverages would require carbon amounts of \$10,000, \$100,000 and \$200,000.

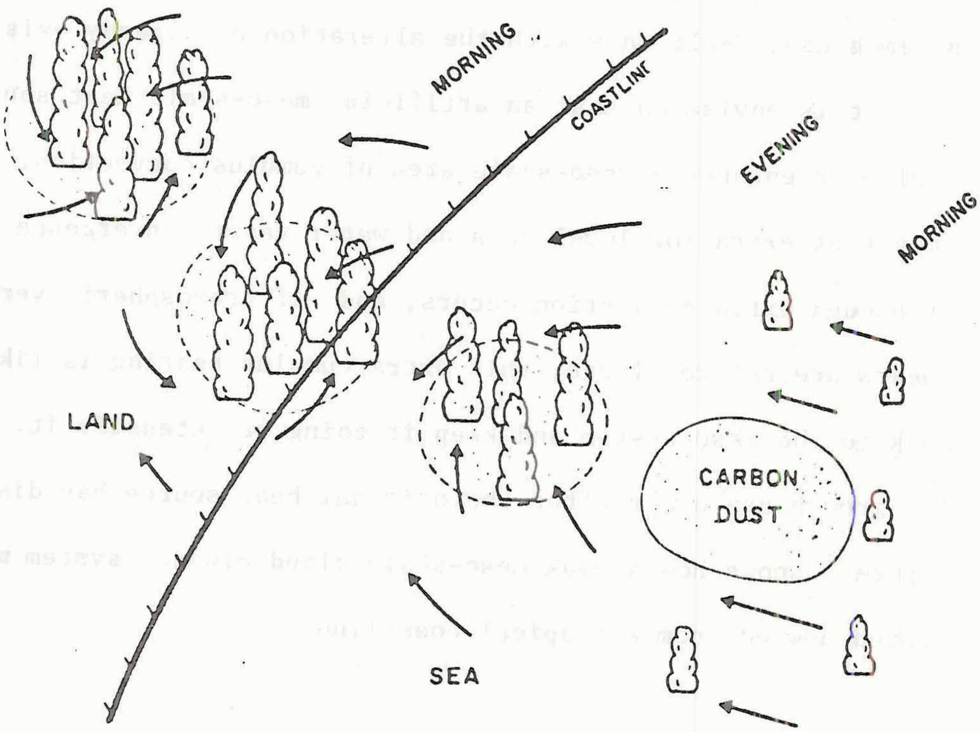

Fig. 4. Plan view portrayal of how carbon dust seeding ½ to 2 days upwind from tropical and subtropical coastlines might act to generate or enhance a weak meso-scale weather system.

Generation of cirrus clouds for agricultural gain. A number of important benefits could be derived if man could artificially form a cirrus shield in the upper troposphere. The authors believe this can be economically accomplished through the dispensing of carbon particles in the upper troposphere. This is made possible by the natural conditions of the atmosphere being mostly transparent to solar energy, the lapse rate being close to the dry adiabatic, and the very high vertical gradients of saturated mixing ratio with respect to water (w_s) and ice (w_{si}) which exist in the upper troposphere. The following table lists what these saturation values are:

Table 2

Pressure Level mb	Temperature °C	Saturation Mixing Ratios for Water (gm/Kg)	Saturation Mixing Ratios for Ice (gm/Kg)
400	-19	2.2	1.6
350	-26	1.4	1.0
300	-34	.7	.5
250	-45	.3	.22
200	-56	.1	.07
150	-67 (in tropics)	.008	.005

The very large percentage change of w_s and w_{si} with pressure should be noted. Saturated mixing ratio values decrease 80 to 95% for air lifted vertical distances of but 50 to 100 mb. Even when air humidity is very low saturation can be obtained for this air by lifting it 25 to 50 mb. This lifting can be brought about by warming the air with carbon particles. Assuming relative humidities with respect to water as low as 50 and 25 percent, the amount of lifting required to bring about saturation with respect to ice can be calculated from the above table. For the temperature lapse-rates of this table, these vertical displacements in millibars and the amount of layer heating required to bring about a dry-adiabatic lapse rate to the condensation level are:

For 50% Relative Humidity with Respect to Water

Vertical Lifting Starting from this Pressure Level	Approximate Amount of Vertical Lifting for Saturation with Respect to Ice	Amount of Warming at Original Level to Bring About Dry Adiabatic Lapse Rate to Level of Saturation °C
400 mb	∿45 mb	∿2.5
350 mb	∿30 mb	∿1.7
300 mb	∿25 mb	∿1.3
250 mb	∿20 mb	∿1.0
200 mb	∿10 mb	∿0.5
150 mb	∿ 5 mb	∿0.5

For 25% Relative Humidity with Respect to Water

Vertical Lifting Starting from this Pressure Level	Approximate Amount of Vertical Lifting for Saturation with Respect to Ice	Amount of Warming at Original Level to Bring About Dry Adiabatic Lapse Rate to Level of Saturation °C
400 mb	∿100 mb	∿4.5
350 mb	∿ 70 mb	∿3.5
300 mb	∿ 60 mb	∿3.0
250 mb	∿ 50 mb	∿2.2
200 mb	∿ 25 mb	∿1.0
150 mb	∿ 10 mb	∿1.0

Summary. It is observed how little upper tropospheric warming and vertical motion are necessary to bring about saturation even when upper tropospheric relative humidities are quite low. It is likely that carbon dust absorption of solar energy can bring about the necessary warming to accomplish this upper level condensation.

Other Methods of Forming Cirrus Shields. It has been proposed that cirrus shields be formed by high flying jet aircraft whose vapor exhaust and turbulence brings about saturation. Condensation trails do form when upper level temperatures are very low or when upper level humidity is high. They often do not form with warmer temperatures or when humidities are low. The condensation trails which are formed in this way often do not persist, and those few which do persist often do not have a major influence on the incoming solar or outgoing IR radiation.

To really influence the troposphere's radiation it is important that rather thick and persistant cirrus be formed. These should be formed in the morning and be able to last through the day and into the night. This can be accomplished, we believe, with carbon particle seeding from jet aircraft. Assuming incoming solar energy in the upper troposphere in a cloud-free sky to be equal to 2/3 of the solar constant ($\sim$ 1.3 cal cm^{-2}min^{-1}) we can estimate the amount of solar heating required to bring about a dry-adiabatic lapse rate from any level to the level of condensation above it for upper level humidities of 50 and 25% as we have previously discussed. We are thus discussing the solar energy requirement to warm air say at 275 mb to bring about condensation at 225 mb or the warming required to form area A on the tephigram plot of Fig. 5.

permit continual solar warming of the layer. This continual solar warming should allow a gradual increase in the cirrus thickness until opacity is reached. At this time the extra solar absorption on the top of the cirrus deck should largely balance the extra IR cooling off of the top (Hall, 1968a, 1968b). If seeding would go on for a number of hours, the latter seeding runs would probably have to go on top of the cirrus shield.

Once a thick cirrus cloud deck is formed with its typical prism-shape - 200 m long, 30μ wide, 5×10^5 particles/m^3 (Weickmann, 1947), it should persist for many hours - probably even through the evening hours. Cirrus particles can last a long time according to Braham and Syrers-Duran (1967).

Assuming a 747 aircraft pay load of ∿ 200,000 lb (and generate ∿ 100,000 lb of carbon dust, see paper by Stokes, 1974) it is seen that one aircraft could generate and dispense 10% coverage of carbon dust (∿ 15% solar interception - see report of Frank, 1973) over an area at the very minimum which is ∿ 500 mi^2 vs the "brute force" method of carrying water to the upper atmosphere of but ½ mi^2. If only 20 to 30 mb lifting were required for higher humidity conditions and horizontal advection of the carbon and cirrus particles are allowed for, the area of cirrus generation with the pay load of one 747 aircraft is likely to be 1000-2000 mi^2. Thus, depending on the number of aircraft used, very broad scale generation of cirrus clouds should be possible.

<u>Conclusion</u>. We thus feel that, by far, the best way in which cirrus clouds can be produced is through a solar absorption mechanism. The direct "brute force" method of carrying liquid water to the upper troposphere is obviously unfeasible for thick and persisting cirrus.

<u>Benefits from artificial cloud production</u>. The ability to form thick and persistent cirrus shields at will could have important beneficial implications for a number of the nation's needs. A cirrus shield could

1) Reduce daytime surface temperatures and prevent the regional formation of "hot spots" in the lowest layer of the atmosphere. If applied during a number of the hottest summer days, this could have a tremendously high beneficial influence on agricultural productivity. Benci and Runge (1974) have recently completed a detailed study for the Department of Transportation showing that the variation of daily high temperature in the U.S. Corn Belt of a few degrees can have a very large influence on corn productivity. According to their model estimates where they isolate the effect of average maximum temperature on corn production they conclude

   > "Based on average long term (1901-1969) cornbelt weather our calculations indicate that corn yield would increase (decrease) approximately 11.3% for each $1^{o}C$ decrease (increase) in average maximum temperature and would decrease (increase) 1.5% for each 10% decrease (increase) in precipitation."

   There may be a number of ways that the formation of cirrus by carbon particle interception of long-wave radiation could be used to enhance the U.S. crop production and also that of other countries.

2) Cirrus cloud reduction of surface heating might also be utilized as an inhibitor of springtime and summer severe weather generation. Purdom (1973) has shown how morning cloudiness can reduce afternoon thunderstorms and inhibit severe weather.

Reinking (1968) has also discussed this. In a combined NOAA-NASA press release of 17 May 1974, Dr. Peter M. Kuhn states

> "the sun is inhibited from forming hot plumes of air over open flat land by the presence of a cirrus cloud cover at altitudes of 30,000 to 40,000 feet. The layers of ice crystals contained in the cirrus clouds block the large input of solar power over the area, reflecting sunlight back into the atmosphere. This results in a cooler earth surface temperature similar to conditions which occur when a sweltering hot day changes to more acceptable coolness with the onset of a cirrus canopy."

3) The cirrus cloud might also be used in a significant way to reduce the severity of early morning frost conditions through the inhibition of long wave radiative cooling. Cox (1968, 1971, 1973) and his graduate students have been studying the influence of cirrus shields on the net tropospheric infrared (IR) cooling and they have found a major reduction in the amount of net outgoing cooling compared to clear skies. Figure compares the IR cooling differences between a clear atmosphere and an atmosphere which contains a thick cirrus shield. The differences in IR cooling between these two environments can amount to as much as ∿ 200 cal/cm^2 per day, or 30-50 percent of the net incoming solar radiation.

There are undoubtedly many other beneficial uses to which the artificial formation of cirrus clouds could be put to use.

<u>Conclusion</u>. It is important that the scientific community explore its capability of artificially manufacturing of cirrus cloud covers for agricultural and other benefits.

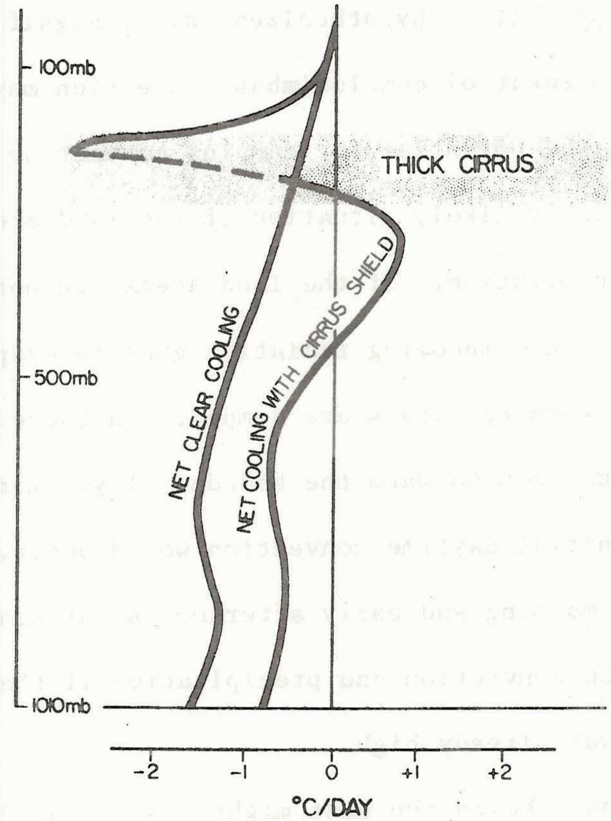

Fig. 6. Comparison of infrared cooling occurring in a clear environment and an environment with a thick cirrus shield, from the information of Cox (1971)

Cumulonimbus enhancement over selected land regions in need of precipitation. It is hypothesized that a significant location change and/or enhancement of cumulonimbus convection may be possible over land areas where the potential for cumulus convection is already high. This is an especially likely situation if the land areas have a high amount of evapotranspiration. If the land areas are moist or have dense vegetation, much of the incoming radiation goes to evaporation or storage and the diurnal warming curves are damped. In these situations the carbon dust could be used to warm the boundary layer more rapidly and to dictate where the initial daytime convection would occur. A localized concentration of the morning and early afternoon solar heating would likely produce extra Cb convection and precipitation if the potential for cumulus convection was already high.

Over land the carbon dust might also be used in selective situations as an elevated heat source (if dispensed from aircraft) and could act as a stimulant to earlier and more concentrated cumulus convection. Especially favorable situations would be areas where large-scale low level convergence is present, such as around low pressure systems and along fronts. Here daytime cumulus convection would be expected to break out in the selectively seeded areas where the earliest atmospheric warming occurs.

Carbon dust heating might thus be used to dictate where the earliest thermal destabilization and cumulus convection would take place. Early morning stable conditions act to inhibit convection. Any large-scale upward forced circulation would likely relieve itself in the areas which first become thermally unstable.

Alteration of extra-tropical cyclones. A significant economic gain might result if weak extra-tropical storm systems could be intensified in dry regions such as the western U.S. This would likely result in extra precipitation. Modest cyclone intensification might be accomplished by warming up selective areas to the east of the extra-tropical cyclone and stimulating extra cumulus convection just east of the storm center. The sinking motion associated with this additional convection should warm and slightly intensify the cyclone. Tracton (1972) has previously indicated that cumulus convection plays a significant role in extra-tropical cyclone genesis.

When cyclones are intense, move slowly, or are stationary, flooding conditions, heavy snow, and high sea conditions can produce considerable economic loss. This is especially true in the heavily populated areas along the U.S. East Coast and in western Europe. Economic benefit would result in some cases if the intense cyclones could be artificially weakened. Solar energy input to the cold center of the extra-tropical cyclone at middle or upper tropospheric levels would likely act to produce a modest but significant cyclone weakening.

Accelerating snowmelt in agricultural regions. There are several large, relatively flat agricultural areas in the world where a snow cover persisting late into the spring can cause a costly reduction in the length of the growing season. The Great Plains of North America and Russia are good examples. When these areas are snow covered, they typically have surface albedos of from 40-90% depending upon the age and condition of the snow and have relatively strong inversions just above the boundary layer. Large amounts of carbon dust particles can be dispensed from inexpensive ground generators into the boundary layer. By warming the boundary layer air under proper conditions it should be possible to accelerate the spring melt of the snowpack, thereby increasing the growing season. The high albedo of the snow surface would cause a strong upward diffuse solar radiation flux and thus increase the efficiency of the carbon absorption. Absorption would take place from both the upward and downward fluxes. In addition, the carbon particles should have a relatively long boundary layer residence time due to the strong inversion which should permit multiple day use of the carbon. This scheme is not to be confused with previous experiments of placing carbon dust on top of the snow, where the mass of carbon to area coverage rates are prohibitive.

Inhibiting the Northern Hemisphere cooling trend. If some of the recent climatological estimates of North American and Eurasian cooling are correct (R. Bryson, Univ. of Wisconsin and many others), then man may be faced with massive new environmental problems in the next few decades. As the albedo of snow of 50-90 percent, a new earth-atmosphere energy gain would be possible from massive carbon dust seeding over snow regions in the spring and summer. Multiple day use of the carbon particles would be gotten as the rainout and washout of the atmospheric particles would be very much less than over regions with active cumulus convection. If one were to comtemplate funding levels as high as 1-2 per cent of the average cost of the Viet Nam war to the United States between 1965-70, then it would appear that this Northern Hemisphere cooling trend could indeed by overcome by extra artificial solar energy gain from carbon dust.

e. Comparison of this hypothesis with previous radiation alteration modification programs

To date, research on the subject of solar weather modification has been centered on fog and natural cloud dissipation and on developing and enhancing inidivdual cumulus. Downie (1960), Fenn and Oser (1962) and Van Straten et al. (1958) have previously discussed the use of carbon.

The Naval Research Laboratory seeded 8 cumulus clouds with 1-3 kg of carbon black in July, 1958 (Van Straten et al, 1958). All of the clouds dissipated to some extent, but observation and instrumentation capabilities were insufficient to establish a definite causal relationship. In addition, clear air at the approximate level of existing cumulus cloud bases was seeded on 5 runs during the same series of tests. Small clouds were observed to form in all cases. Once again it was impossible to establish definite causal relationships. The overall feeling of the test group was that the carbon black did seem to help dissipate existing clouds and form small ones in clear air, but the natural variability of cumulus clouds and the inadequacy of monitoring techniques prohibited any conclusive results.

Laboratory tests by the Naval Research Laboratory in 1958 showed that carbon black did increase dissipation rates of artificially created fogs in cloud chambers which were subjected to heat lamps. However, neither the dissipation mechanism nor the radiative properties of carbon black were quantitatively well established.

The Geophysics Research Directorate made 18 runs seeding small clouds and clear air in October, 1958-April, 1959 (Downie, 1960). Carbon amounts from 1-3 kg per mission were used. Results were less successful than those observed earlier by the Naval Research Laboratory. A few clouds dissipated, but others did not. Clear air seeding produced no obvious results although a few small clouds occasionally formed in the test areas. The test personnel concluded that no definite effects of carbon black on clouds could be substantiated through their test results.

In general, these early experiments with carbon black suffered from four major shortcomings:

1) The existing knowledge of the radiative properties of carbon black was entirely inadequate to provide realistic estimates of the energy processes occurring in the atmosphere.

2) The amounts of carbon used were much too small. Small scale diffusion effects could easily dissipate the heat absorbed and overpower the effects of the heat accumulation.

3) Severe logistical and clumping problems associated with the handling and dispersal of the carbon particles were encountered.

4) Adequate observation and instrumentation capabilities to enable conclusive analysis of field test results were not available.

The previous research by C. Downie and B. Silverman* (U.S. Air Force Cambridge Research Lab.), F. Van Straten*, R. Ruskin* (U.S. Navy Research Lab.) and T. Smith* (Private Industry), etc., in general, proved not to be promising. The amounts of carbon used (5-20 Kg) were not consistent with the purposes. Dispersing and clumping problems were encountered. Previous work in the late 1950's and early 1960's was conducted on a scale (generating or intensifying individual cumulus) and with a technology (dispersing already manufactured carbon) which is entirely different than the one proposed in these papers.

By contrast, this research is concerned with the feasibility of carbon particle modification on the meso-scale (~ 100-200 km on a side) using amounts of 1-2 million Kg. We are planning to directly manufacture the carbon dust on aircraft or from carbon particle generating sources on

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*Personal communication

ships or at surface sites. By direct manufacture of the carbon black dust from field sources, one avoids the clumping, packing, and logistical problems involved with using carbon particles obtained from the factory.

f. Coating surfaces with black material

The ESSO Oil Company of New Jersey (Black and Tormy, 1963a, Black, 1963b) has explored the possibility of boundary layer heat augmentation from coating land surfaces with black-top (tar). These results have not been very encouraging. The black-top program has suffered from three basic drawbacks:

1) The surface air blows over the few miles of black tar field in just a few minutes. Only a relatively small heat input can be made per unit mass of air. The carbon dust scheme, in contrast, has the carbon particles moving with the air mass. The energy input over a number of hours can be very large.

2) The land surface would naturally warm up and heat the air above to an appreciable extent without the black tar. The black top heating is only the difference between its heating and the natural surface land heating which would normally occur. In contrast, when applied over the ocean, nearly all of the solar absorption by the carbon dust is extra energy gain relative to the surrounding air.

3) The envisaged area coverages of the black top of $\sim 100\ km^2$ are too small to have a significant influence. By comparison the authors are proposing the carbon dust heating of area amounts equal to 10,000 to 100,000 km^2.

3) How will the carbon warming affect the vertical diffusion and advection of the carbon dust during the heating day? How will the shielding of the carbon by the clouds affect the energy gain?

4) To what extent will the artificially enhanced cumulus convection act as a 'feed back' mechanism to further intensify the meso-scale flow system in which it is embedded?

i. Synopsis

Many previously unexplored avenues of beneficial utilization of solar energy may be available to man. It is time for man to explore these areas of potential meso-scale weather modification. The discussion in this paper is very different than most current weather modification schemes which concentrate on alteration of individual cumulus elements.

j. The following research reports and conference proceedings discuss this subject in more detail.

RESEARCH REPORTS

1. William M. Frank - "Characteristics of Carbon Black Dust as a Large-Scale Tropospheric Heat Source". Atmospheric Science Paper No. 195, 1973, 52 pp.

2. William M. Gray - "Feasibility of Beneficial Hurricane Modification by Carbon Dust Seeding". Atmospheric Science Paper No. 196, 1973, 130 pp.

3. William M. Gray, William M. Frank, Myron L. Corrin, and Charles A. Stokes - "Weather Modification by Carbon Dust Absorption of Solar Energy". Atmospheric Science Paper No. 225, 1974, 191 pp.

   a. Paper I. - "Background Information and Hypothesis" by William M. Gray and William M. Frank.

   b. Paper II. - "Radiation Characteristics" by William M. Frank.

   c. Paper III. - "Generation of Carbon Particle Clouds" by Charles A. Stokes, Sc.D.

   d. Paper IV. - "Environmental Impact" by William M. Frank and Myron L. Corrin.

   e. Paper V. - "Evidence for Hypothesis and Proposed Research Program" by William M. Gray and William M. Frank.

CONFERENCE PROCEEDINGS AND TALKS

1. Frank, W. M. and W. M. Gray, 1973: Characteristics of Carbon Black as a Possible Large Scale Weather Modification Agent. Paper presented before AMS Eighth Technical Conference on Hurricanes and Tropical Meteorology, May 14-17, 1973, Miami, Florida.

2. Gray, W. M. and S. L. Rosenthal, 1973: Proposed Use of Carbon Black as a Hurricane Modification Agent. (Paper presented before AMS Eighth Technical Conference on Hurricanes and Tropical Meteorology, May 14-17, 1973, Miami, Florida).

3. Gray, W. M., and W. M. Frank, 1973: Feasibility of Meso- and Synoptic-scale Weather Modification from Carbon Black Dusting. Paper read at WMO/IAMAP Scientific Conference on Weather Modification. Tashkent, Russia, Oct. 1-7, 1973.

4. Gray, W. M., R. E. Lopez and W. M. Frank, 1974: Feasibility of Precipitation Augmentation by Carbon Dust Seeding. Paper appearing in proceedings of the WMO/AMS International Tropical Meteorology Conference, Nairobi, Kenya, Jan. 31-Feb. 6, 1974, 18 pp.

5. Elsberry, R., E. Harrison, and W. M. Gray, 1974: Simulation of Development of Mesoscale Convection Regions by Artificial Heat Sources. Paper appearing in the WMO/AMS International Tropical Meteorology Conference. Nairobi, Kenya, Jan. 31-Feb. 6, 1974, 6 pp.

V-11. LARRY TOMBAUGH*, STAFF ASSOCIATE, ENV. SCI., NATIONAL SCIENCE FOUNDATION

Lew, I hadn't planned to say anything, but I was concerned about the perspective that may have been left by Dr. Chamberlain's remarks although I certainly didn't disagree with a thing he said. I think there is. however, another perspective that might be brought to bear on the issue that we are trying to address and I would just like to throw it out for your consideration. I am certainly not trying to sell the idea but I would be interested in your feedback. The perspective comes from the environmental side of things.

We put, in this country, several billions of dollars over the last 10 years into environmental research, practically all designed to control the kinds of environmental problems caused by man, pollution problems generally. It is my hunch, and I could be dead wrong, that over the next few years we are going to learn that as we bring air and water pollution problems more under control, that low and behold we will be faced with a whole array of other problems that are basically environmentally caused. We are going to find that once we get to where we thought we were going, we are still not going to have man comfortably into a justaposition with his environment so that the quality of life is going to be what we thought it would ten years ago. We are still going to have hurricanes, tornadoes, earthquakes, crowds, those many environmental issues that directly affect the quality of man's life. Now, it turns out that there are, it seems to me anyway, several mitigation devices or techniques for these many kinds of environmental risks or hazards. We can think of land use planning, we can think of engineering approaches. One thing is clear it seems to me and it comes from the energy experience; there is probably no panacea. There is probably no single way to get at, control, or mitigate these many environmental risks or hazards this country faces. It would be foolish it seems to me, to pursue any one course of action. It seems to me that Dr. Chamberlain is dead right, that we are probably not going to, through the weather modification route, answer all the world's food problems, we are not going to make all mankind more comfortable with his physical environment, but we are going to make a small inroad in that area. Inroads in say drought reduction, or the many kinds of potentials that Eric Walther and others have alluded to here. If we put this activity that we are embarked upon here today into that context, into the context of making a small step in a big spectrum of activities to improve the quality of life, we may be a little better off.

Now I want to make one other point very quickly, one of the problems that Dr. Chamberlain and everybody has alluded to is the problem of acceptability of weather modification. I have had the great fortune in the last two days of being down at NCAR and heard what I considered to be a splendid presentation by a representative of the University of Colorado. The part that really captured my imagination was Barbara Farhar's presentation. I am going to use some of her ideas here concerning what she viewed as the five major characteristics of innovation and the adoption of innovation. Let me just quickly run through those. I submit that in the report you people are going to be working toward you might want to seriously consider somehow working in these ideas of the characteristics of the innovation. The <u>first</u> one was the <u>relative advancement of the innovation</u> and in this case where the advantage is: Well, the question is, is it better than the thing it supercedes in this case we are trying to supercede mother nature and the reason we have got a problem is that occasionally mother nature is not as bountiful or perhaps more bountiful than we would like her to be. And so it seems to me that weather modification does offer some relative advantages. The second point that she brought to our attention was the issue of compatibility. Compatibility in terms of the ethics, ethos, morays, and folkways of society. We have a little bit of a problem here, we are tampering with mother nature. That is one of the items that should be given some thought to if we are going to be effective in our activity. Third is complexity, is the technology of innovation understandable. Can we explain it to the legislators, to the many people we have to do business with, and we have a problem here too, it seems to me. Let me come back to compatibility for a moment. Weather modification is a little indifferent here. There are people who are considerably very much in favor of weather modification, in favor of trying to see what we can do to better meet the needs of the agricultural community through weather modification. Fourth point, trialability, the degree to which we can try the innovation on a limited basis and we do have a problem here. The scaling up problem is serious from laboratory to major field experiments. It is one of the difficulties we should keep in mind. Fifth, observability is the issue of whether or not the man on the ground can really see the effects of what you are doing basically, and often again in the weather modification business that is a problem. So when we think, it seems to me, about the issue of acceptability, if we approach it on a somewhat scholarly basis, we may be able to couch our report in terms that will enable us to at least see if we can overcome some of these issues.

V-12. D. E. SCHLEGEL, CHAIRMAN OF PLANT PATHOLOGY, UNIVERSITY OF CALIFORNIA

Crop protection is a general term used to describe in a broad way those activities specifically designed to protect crops. Weather affects crop protection, consequently, weather modification has serious implications for crop protection systems. To my knowledge there have been no direct studies on this interaction, however, there is a considerable volume of literature on the effects of environment on the epidemiology and ecology of diseases and insects. An example of the concern agriculturists have for weather is seen in the September 75 meeting of British Association of Applied Scientists. The entire week long meeting is devoted to crop-weather inter-relationships.

Because participants in the present workshop represent a wide variety of disciplines and the terminology and jargon of each varies widely, particularly between the fields of meteorology and agriculture, a few definitions are probably in order.

Plant pathology is one of several disciplines concerned with plant protection. Other disciplines include entomology, nematology, and weed science. Plant pathologists deal with a number of types of organisms causing disease, e.g. viruses, fungi, bacteria, mycoplasma, parasitic plants, etc. The destruction caused by these organisms, with a few exceptions, is heavily influenced by the environment -- particularly moisture. Integrated pest management is a system of crop protection which utilizes all possible ecological sound control procedures to keep pest levels at or below an economic threshold. Pesticides may be a component in this system but they are generally integrated with various environmental, cultural, and genetic manipulations to achieve a control.

Small shifts in micro-climatic conditions often determine whether or not a specific pest will become a problem during a particular growing season. The general tendency is for pest problems to increase with increasing humidity, thus the concern for possible adverse effects of climate modification are well founded. Generally, increases in humidity and temperature increase pest activity but this is not universal. Effects will depend upon distribution of moisture.

The effect of a pest may be dramatic or so small as to be difficult to assess. Even those pests causing minimal damage are likely to be quite important, because they result in a steady or continual reduction in yield or income. Production costs do not decline with losses due to pests as most costs are fixed -- e.g., land preparation, planting, irrigation, cultivating, pruning. Costs may even increase if control measures for the pest are taken. Thus, a 10% reduction in yield due to the action of a particular pest may seem relatively inconsequential, however, if production costs equal 60 to 80% of the market value of the commodity this 10% represents 25 to 50% of the net income from the crop. In developing countries bordering on famine the pests take their ration before the poor of the country get theirs.

Plant Diseases: As mentioned above, plant diseases are caused by a wide variety of microorganisms and viruses. Their mode of activity and the losses that they cause vary widely from disease to disease and crop to crop. In some cases, when seeds are planted they rot before they germinate. The result is a poor stand and reduced yield. In other cases, good stands are achieved, but the disease strikes during the growing period of the crop. The affected plants may be reduced in vigor or even killed. In either case, the crop yield is reduced although the quality of the product may remain acceptable -- or it may be reduced. In other cases diseases strike the commodity being grown for sale and cause major reductions in quality due either to the direct destruction of the product, reduction in quality of the product, increased harvest costs, or development of toxic materials in the food crop. Regardless of the type of damage, less food and fiber are produced, and there is usually a loss in income for the grower. Where toxic compounds develop, there is also a potential health hazard to the public.

Insects: Insects are recognized as the cause of crop losses by a larger proportion of the population of the world than other pests. The reason is quite clear. The insects and the damage they do can be seen by the farmers. Masses of insects feeding on a leaf can be seen readily and damage associated with the feeding action is recognized. An apple riddled by the larvae of the coddling moth is not very salable in competition with higher quality products. Few housewives like to find a corn ear worm feeding on an ear of corn purchased at the market. The gypsy moth, and the spruce bud worm are threatening huge acreages of forest on the east coast.

Weeds: Weeds cause hugh losses in many agricultural systems. Their principle effect is to reduce yields through competition for light, moisture, and nutrients. Additionally they can interfere in harvesting procedures and end up as contaminants, lowering the grade of the product. Some weeds are parasitic on green plants and as such represent a direct drain on the production capacity of the crop. Weeds also serve as hosts for many plant diseases and insect species. Insect pests flourish on weeds and as the weeds mature and the insects leave, looking for more appetizing surroundings in agricultural crops. Some of these insects carry with them diseases, usually viruses, which may be transmitted to crop plants. Other weeds are infected by diseases which then spread to the agricultural crops in the community.

Nematology: Nematodes are a serious soilborne pest and are widely distributed. They may cause direct damage by feeding on the root system of a plant and some even transmit viruses. They are not, however, as likely to be influenced by brief rains such as those obtained by weather modification procedures.

Rodents: Rodents include animals such as gophers, rats, squirrels, rabbits, etc. These animals do their damage by killing the plants or feeding on the plant material. In many areas of the world, where rice is grown, rats get an almost unbelievable percentage of the crop. In such countries active rodent abatement programs are usually underway. It would not appear that these pests would respond significantly to the generally small amounts of precipitation released in weather modification procedures.

Weather Modification in California

There are a substantial number of weather modification programs underway in California. All of these programs are over mountain areas where the primary goal is to increase spring runoff to provide more hydroelectric power and/or more water for use during the dry summer months. Some summer seeding has been done, but generally this has been in the higher elevations.

This rather unique situation in California minimizes the influence of weather modification on pests because it does not bring about sudden changes in the climate affecting agricultural crops. Because most seeding is done during the dormant winter and early spring months, there appears to be little effect even on the forest ecosystem. My forest pathology friends say, however, that a significant increase in summer and fall moisture could have some very striking effects on spread of certain foliar diseases. They expressed real concern about the months of September, October, and November. However, there has been essentially no activity in those months in California.

The situation in the corn belt is likely to be quite different from that in California. Each period of rain is accompanied by a period of very high humidity and it is during such periods that aerial pathogens really begin to move. Bacterial and fungal pathogens move as aerosols in the wind. California farmers installed their own weather modification equipment beginning in the '50's. They turned to overhead sprinkler irrigation instead of the furrow irrigation used until that time. This resulted in huge acreages being watered from overhead sprinklers and the foliage was wet every few days. With the very high temperatures of the area humidities in the microenvironment at plant levels soared to unprecedented heights.

The results were predictable - the diseases of the midwest appeared everywhere. Angular leaf spot of cotton became very abundant - it has never been seen before. California growers had for years supplied the dry bean planting seed for the country because the hot dry summers prevented disease organisms from being established. With the introduction of the sprinklers all the disease that had been avoided previously became serious problem.

Weather modification holds broad implications for pest control activities in addition to the direct action of moisture and temperature. Pest management systems involve various types of pesticide applications and certain of these can be greatly reduced in effectiveness by untimely rains. Thus, close coordination is needed. Disease and insect forecasting is really only just beginning, and is tied inextricably with weather and weather forecasting. To the extent that weather modification activities may change forecasts there will be conflict which will have to be resolved. Therefore, it is essential that there by a two-way communication between the weather modification people, weather forecasters, and crop loss forecasters. Temperature is the other most critical environmental factor, and if manipulation of this factor becomes possible, the concerns expressed above also apply.

V-13. DALE LINVILL, DEPT. OF AGRICULTURAL ENGINEERING, MICHIGAN STATE UNIVERSITY

Weather Modification in Michigan

After experiencing several seasons of inadequate precipitation, farmers in three mid-Michigan counties (Gratiot, Isabella, Montcalm) formed non-profit corporations to conduct cloud seeding in their area. Their first operational period was the summer of 1972. Since that time cloud seeding has spread to other areas and is active this summer in several Michigan counties.

Prior to embarking upon a cloud seeding program, many of the counties approached the Agricultural Experiment Station seeking information about rainmaking. Although information was limited and our expertise in cloud seeding almost non-existent, the extension staff welcomed help of any sort that we could offer. We made numerous presentations around the state telling of the variability of summer time rainfall and what we knew about current cloud seeding technology.

Since agricultural groups were originally responsible for cloud seeding re-entering the state and since it represented a potentially large dollar drain on Michigan's economy, a monitoring and evaluation program was initiated within the experiment station under the direction of the Department of Agricultural Engineering. Existing National Weather Service weather stations were augmented with dense rain-gauge networks in the areas. This program has expanded to now include counties inside and outside the target areas. Computer analysis of all rainfall data allows us to keep up with current conditions.

Past analyses have been limited to post mortums of each season's rainfall. 1975 marks the fourth year of cloud seeding in the original target area. Combining data from all years should show precipitation pattern changes due to cloud seeding if they are present.

We have examined Detroit radar data for 1973. It revealed a significantly greater number of returns initiated within the target area than within adjacent areas. Radar data from other years will have to be examined to determine if indeed cloud seeding was responsible for the radar returns.

Comparisen of the contractors reports (I.P. Krick's group) and our analysis revealed a problem with base normals. In Michigan the difference between 1911-1940 and 1940-1969 normal precipitation amounts to about 10%, the same order as can be attributed to cloud seeding. If an analysis uses "percent of normal" to show rainfall distribution, the results could be misleading to a lay reader. We are careful to caution our extension staff in the interpretation of normals and percent of normals and the effect of the base period.

In depth economic analysis of weather modification in Michigan has not been attempted.

Weather Modification Research

In the past, climatologists have used the calendar month to break down meteorological data. Climatological analyses need to be done on periods other than a calendar month in order to account for crop growth periods. Effects of precipitation upon crop growth could be determined easier if the data were available on shorter time periods and combinations of periods. This is especially important when differences in planting and harvest dates are considered.

Such analyses can also give some insight into location and timing of rainfall maximums and minimums. Models such as those proposed by Changnon can then help identify areas and time periods where cloud seeding may be profitable based solely upon historical data.

Rainfall analyses in conjunction with cumulus cloud climatology perhaps from radar data can help separate the types of rainfall, causal agent, and amounts received in an area. Since each situation may require specific cloud seeding techniques, these climatologies can aid in the design of operations in specific areas.

The cumulus cloud modeling being undertaken by several groups needs to be encouraged. Much of the rainfall during the summer months comes from cumulus clouds. Their dynamical and physical processes must be understood before seeding can be a viable operation.

The study of cumulus cloud dynamics can also lead to a better understanding of plume characteristics. The controversy between ground based and aircraft seeding demands an answer. It will not be found until some good hard work is put into ground generated plume studies.

This leads then to inadvertent weather modification. Such things as rainfall Ph change and variation over space need further study. What is the effect of dust clouds generated in farming activities or odors released by other activities? Plume studies will also help answer questions in these areas.

The role of ozone and where is it produced comes under this heading. Dry bean production in Michigan is showing the effects of ozone damage probably from inadvertent weather modification.

Another aspect of weather in Michigan is sunshine. We are blessed with the Great Lakes on three sides of our state. They help generate cloud cover that at times we could do without. Studies on the dissipation of stratus decks should be undertaken to increase sunshine during critical growing periods.

And finally, has anyone undertaken an independent study of operational cloud seeding projects that have been underway for a number of years in several areas? This could be very beneficial to determine if indeed the claims for cloud seeding stand up under careful scrutiny.

ADDITIONAL INPUT

Weather Modification in the Microclimate

The preceeding sections stressed large scale weather modification programs. There are, however, several types of modification that need to be done on a local or field scale. Many techniques are already thoroughly researched and what is needed are sound educational programs for farmers demonstrating their genefits. Small annual windbreaks would fit into this category.

A promising area in need of work is heat/moisture stress control through mist irrigation. Some work has started on orchards and truck crops with the technique slowly becoming practical.

Radiation control in crop canopies may be a misnomer. We can only (profitably) work with what Mother Nature is supplying. However, crop architecture is an important control mechanisms as is crop-soil albedo. Artificial control of light in orchards through reflectors is one possibility of such weather modification. Other high value crops can also be identified that could profit from light modification expecially those crops with critical light needs.

We must not forget animals and insects when we discuss weather modification. Altering local climates through crop canopies or buildings can lead to or alleviate many stress conditions for animals and insects. Although local in nature, they can be very important. Once again, many of the techniques are in existence and what is needed is education to see them implemented.

In this respect, what is needed is a method of appraising local climatological conditions so that on site recommendations can be made with a minimum of local data.

V-14

J. Baker Gratiot County, Michigan

WEATHER MODIFICATION PROGRAM FOR GRATIOT COUNTY, MICHIGAN 1972-1975

The Gratiot County dry navy bean and corn yields appear to be in direct relation to the amount of rainfall that they received during the last two weeks of July and the first two weeks of August.

The 1971 season was very dry and the county corn yield was 65.1, the bean yields were 9.3 cwt. Many of our farmers asked me to look into weather modification. I asked for and received 2 months sabatical leave. I traveled to areas in the U.S.A. that had weather programs and talked with both commercial and government weather people.

We hired the Irving P. Krick Co. for the summer of 1972-73-74. They are under contract again for this summer. They provide our farmers with two services: 1) a weekly weather report and also a long range report for the entire growing season and 2) weather modification program for the months of June, July and August.

How have the farmers liked the program? They all feel that the weekly weather report is very good. Most feel that they get more rain from this program (the main disadvantage is that some bean and pickle growers feel they got too much).

How is the program financed? The farmers have a drive and try to collect 50¢ per acre from those that will give. The cost runs $1,000.00 per Township (36 sections).

Who controls when you activate the generators? Each Township elects a director and it takes a 2/3 vote of these directors.

Did It Work?

I don't know. We appeared to get more rain when the generators were on then the area outside the program. But summer rainfalls in Central Michigan always have been very spotty. Maybe we were lucky for three years.

Our crop yields were very good. The average corn yield in Gratiot County for the three years was 92.3 bushels, the State average was 71 bushels. Again, maybe we were lucky.

I have a few suggestions: Much work needs to be done on monitoring rainfall not only on total amount of rainfall but maybe more important for our area, intensity of rainfall. One inch of slow, small droplet rain can do a lot of good, two inches of violent large driving rainfall can hurt us.

There should be a large educational program explaining what you can and cannot do. When you're doing it and what the results are. People should know that every time they get a rain that it wasn't caused by the program. The Agriculture Extension Service can play a big part here.

Weather affects everyone and should be financed and controlled by the government with a local appointed board to advise on conditions. Weather affects vacationers, sportsmen, etc. both from too much rain and too dry. The D.N.R. and the Department of Agriculture should both be in on this program.

Cloud Clearing

We should not stop at just rain making. The northern United States has a short growing season. We should consider cloud clearing, using silver iodized, NH_3 or what ever it takes. Five more sunny days in September and early October would save a lot of energy in drying corn. Soybeans and dry beans would have much better quality if we could harvest them in sunny weather. This would be a very easy program to sell as everyone wants sunshine.

I believe the biggest boom to crops for the last quarter of the 20th century will be weather modification.

V-15. JOANNE SIMPSON*, PROFESSOR OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF VIRGINIA

My work in weather modification has involved looking at the scientific feasibility of weather modification. What I'd like to take up as an agenda item with this group today is what might be called the transfer function from the demonstration of the scientific feasibility to how the demonstration is going to be used to help with food production. In order to do that we have to start with where we stand in feasibility and not only where we are right at this moment but where we are likely to stand in the next five years and the next ten years. Actually I come from what might be called the conservative or right wing portion of the scientific community and frankly this is the first time I feel that the feasibility demonstration is far enough along in weather modification so that I personally consider it a worthwhile to address a conference and participate in a conference on this topic. I do not share the pessimistic noises that are fashionable to be made in many circles about weather modification today. I think we have more reason to be optimistic today than we ever have had before. I would like to start with the feasibility baseline to demonstrate that and then make suggestions on how we go on the transfer from feasibility to usefulness.

Let us consider three areas of weather modification which are somewhere between demonstrated and hopeful, as feasibility.

1. Precipitation augmentation
2. Hail suppression
3. Hurricane mitigation

I believe if the experiments that are on-going and planned and hurricane mitigation actually fulfill their promise and it is found that the destructive effects of hurricanes to some extent can be modified -- this can be an enormous benefit to food production. One hurricane can wipe out a whole or several whole crops in a key food production area. So, although this is not a demonstrated concept as yet, it is a hopeful one and one that food production people ought to keep their eyes on.

Let us move from there to hail suppression. Hail suppression, there has been no conclusive demonstration by a properly controlled scientific experiment that hail suppression will work. However, I will bet you a beer that within the next five to ten years there will be such a demonstration. This is a very hopeful area of weather modification, and one in which many promising soundly based operational programs are underway in several places in the world. I am going to save precipitation augmentation till last and say a little bit more about hail suppression first. Hail suppression has a different character from most aspects of precipitation augmentation because it is used on a fire fighting basis. And we wanted to distinguish between use on a fire fighting basis of weather modification and use on a long range basis. In a hail suppression project people are learning how to identify hail producing clouds, they have their aircraft in readiness, they run out and treat these clouds as they are approaching these so called protected areas, and the benefits, if there are any benefits, are immediate. In precipitation augmentation we have an entirely different situation. In most cases we have two different situations which I think we ought to distinguish between in this conference. One, the fire fighting type of situation, where we may be able to do something right at the time there is a drought or the growing season, is crucial and the farmers need the rain. We'll talk about this in a minute. And then the most conclusively soundly demonstrated precipitation augmentation experiment's are ones that are wintertime precipitation situations, wintertime cyclonic storms, in Israel in particular, and in several places in the U. S. such as Santa Barbara and Australia where it is sound and has been demonstrated conclusively and the rainfall can be increased something on the order of 15-20% by scientifically sound controlled experiments. However, let me use Israel as an example because I think this is one place where they have gone not only through the successful demonstration of the science but the actual application to the water resources in the agriculture of the country. The seeding has been shown over an 11 year period to make a 15-20% increase in the winter season rainfall. The seeding is done in the watershed of the main reservoir of the country which applies to the main aquafer of the country. Hydrologic calculations have been made that show how much of this water evaporates, how much of it runs off, how much of it becomes useful to food production. I was over there looking at this experiment and it's very interesting that the food production is not just the kind of food we think of in crops but is also fish farms. Right off the River Jordan where the water from Lake Tiberis is flowing down the main aquafer, there is some of the most successful fish farms in the world which are also being aided by the demonstrated water increase to the water supply of the nation. But this is the kind of thing that requires planning through a number of centers. You don't just start screaming when there is a drought, because in the dry season in the summer there is no rain. There have been plans made to hold the rain from the wet season and make it available in the dry season. Unfortunately in many of the successful precipitation increase experiments in this country such as the orographic snowpack which is another area where we have had conclusively successful results, I am not sure whether or not the concrete steps have been taken to take the increased snowpack in the winter and somehow see how much of this can be made available to food production. How it is to be made available to food production and this is a topic well worth consideration.

Now, I want to conclude briefly on the fire fighting aspect. I am not as pessimistic, in this area of weather modification as some other meteorologists are. We had some opportunity to bootleg a drought study in our Florida cumulus program. I bootlegged as much of this as I could till the management caught up with me and we learned very interesting things about drought. For one thing, in the most severe drought on record in Florida, there was one day in three in which dynamically seedable clouds were available in fairly significant quantities. I am not sure this would be true in other non-tropical places, but at least in a key watershort area there were periods within the most severe drought on record when there were seedable clouds available. It was also interesting to note that the drought was much more pronounced over the land than it was over the surrounding water. We had a radar which made a comparative study of the drought conditions over the land and over the water. There was something that was going on in the interaction between the particles and the dynamics that was aggravating the drought over the land. I think we ought to undertake much more careful studies of drought because I am optimistic that something can be done about it. And I think Arnett Dennis and his collaboraters in North and South Dakota, which is the topic I want to conclude on, show that there is a growing season when they made cumulus experiments and carefully stratified the data so that they were working on showering clouds and relatively undisturbed atmospheric conditions. They had something like a factor of two or three increases in precipitation and it was during the crucial time of year for crops. So I think we can both pursue the fire fighting approach and the storing approach at the same time. I hope that we can discuss these topics further during the coming meeting.

V-16. ARNETT DENNIS*, PROFESSOR OF ATMOSPHERIC SCIENCE, SOUTH DAKOTA SCHOOL OF MINES

The message I want to give to the members of the bride's family, they sit on the right don't they? is this. Don't judge the present state of weather modification technology by what was published prior to 1965 or anything that was done by a distinguished panel consisting of people over 65 that was published before 65, because all of that stuff is out of date very badly. Not the people, just what they said.

The point is, we have now finished a second generation of cloud seeding experiments in which we brought in, in a small way, and I repeat, in a small way, such techniques as data stratification, proper use of covariate analysis, the first beginnings of computer simulations of experiments or what we call Monte Carlo techniques and very importantly the use of cloud models in prediction of seeding effects. Dr. Kessler of the National Severe Storms Lab put it beautifully at the Third Conference on Weather Modification when he said "cloud models demonstrate what they are supposed to demonstrate." So don't buy the cloud models uncritically. But properly used, the cloud model can help. What a cloud model related, computer related, radar related, experiment does show is that the cumulus clouds of the northern Great Plains are susceptible to modification. Some of them are susceptible. At the present time we think the clouds which are susceptible exist in the proper quantity of time and space distribution to permit that one inch of extra precipitation per growing season. But for heaven's sake, don't ask it to be delivered the week that the corn tassels or that the June bugs come out, or anything of that kind. We are talking here about an infant technology. The question is not is this a perfected technology, but is this infant technology now at the point where we can justifiably present it to you and say, is this any good? Would this help? I hate the word palliative because that seems to play it down too far, but is it enough to make a real contribution? My estimate of an extra inch of growing season rainfall, I am a little more optimistic than Joanne, about hail suppression. I think there is a hail suppression effect and that it is of the order of 50%. But as I say, these are estimates which will be further refined.

We now have an obligation, having done this generation of experiments, to convey the results to you and the users. We also have to convince some of our fellow meteorologists who haven't had time yet to get through the numbers. It took ten years to thrash out what Arizona One and White-top had to say. And it took that long on experiments which really didn't have very much to say. What is it going to take about the current generation of experiments or the ones just passed like the Florida cumulus, some of our work, the work at Flagstaff, Israel, Soviet Union, so on. The HIPLEX part of Skywater I predict will not be telling us anything before at the earliest 1982-1985. For one thing, they haven't finished the environmental impact statement. We had the advantage we didn't have to write one. Of course, we have a lawsuit, which is something else. We are going to lay the numbers out for you. I will do it in the working session. We are putting them in the August issue of the Journal of Applied Meteorology. And if you think that is the last of what you are going to hear about the northern Great Plains, you're crazy. Because I am going to keep talking to you until you are sick of hearing me. The inch of rain is there. What you do with it is your business.

V-18. EVERETT RICHARDSON, PROFESSOR & ADMINISTRATIVE ENGINEER, CIVIL ENGINEERING, COLORADO STATE UNIVERSITY

Enhancement of Snowpack in the Mountain Ranges of the West

Irrigated agriculture, in deference to its critics, is an important aspect in food production of the nation and to the economics of the 17 western states.

Irrigation water is in short supply in most river basins, particularly the Colorado River Basin, Rio Grande Basin, Arkansas River Basin, Platte River Basins. Additional water would increase production of food and in particular, foods that have high market values such as sugar, citrus, and various vegetables. Most of the water would go to the desert area where, with adequate water, continuous cropping can be done.

The value of this water ranges from \$2.5/acre foot to \$100/acre foot. Cloud seeding costs produces water about \$2 to \$3 per acre foot.

Additional water would alleviate the decrease in irrigated acreage that is presently taking place by urbanization. Every acre of land that changes from agriculture to urban requires approximately the same amount of water as one crop of irrigated agriculture. Thus, land lost from agriculture to urban area cannot be replaced, even though land may be available.

Additional water is needed to help decrease the salinity of the stream. This is particularly true of the Colorado River.

Snowpack water is needed to produce the energy needed by agriculture. This energy can be in the form of hydropower. But more importantly, vast amounts of water are needed for coal liquification or gasification, and oil shale conversion. For example, it takes:

a. 20,000 AF of water for 100,000 barrels of oil from coal
b. 10-45,000 AF of water for $7x10^6 m^3$ of gas from coal.

Snowpack water is needed for reclamation of the land that is disturbed by strip mining. The water for energy and land reclamation is and will be in short supply in the Colorado, Yellowstone and parts of the upper Missouri River Basin.

These river basins -- Colorado, Rio Grande, Arkansas, Platte, Yellowstone and upper Missouri -- can use all the water that can be produced by snowpack augmentation without damaging the ecology of the high mountain area. The snow produced will increase forest products as an additional by-product in addition to hydropower.

Implementation

Pilot programs in the Sierra and Rockies have developed the technology. The technology is available. Action is needed to implement a large scale program managed and financed by the federal government. It could be financed by a fee on all water diverted for agriculture, industrial or domestic use. This fee would probably be less than 0.10 cents per acre foot, if applied uniformly to all diverted water in watersheds where augmentation takes place. All users would benefit -- albeit some more than others but by assessing all users, the assessment would be small, cost of collection small, and a sustained flow of money would be available.

Studies need to be made of where to augment, when to augment, appropriate methods for each site, the environmental impact, potential gains in water and costs.

Additional base line data should be collected before and after seeding programs are initiated. Data needs are stream flow, precipitation, water quality, temperature and solar radiation. Mathematical models of each watershed should be developed to hold design of the weather modification program and to monitor the results. Public information should be continuous and timely.

V-19

WEATHER MODIFICATION IN NEBRASKA

R. E. Neild
Professor of Agricultural Climatology
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Lincoln, Nebraska

July 1975

Paper prepared for the workshop, "An Assessment of the Present and Potential Role of Weather Modification in Agricultural Production," sponsored by the National Science Foundation, hosted by Colorado State and Michigan State Universities, Fort Collins, Colorado, July 15-18, 1975.

Weather Modification in Nebraska

R. E. Neild, Professor
Agricultural Climatology
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Large variation is a characteristic of Nebraska's climate. Efforts to modify or otherwise cope with these weather uncertainties are traditional activities in our agriculture. We are vitally interested in any promising control of weather. We will quickly adopt what is practical. Following is a brief review of some of our efforts in this regard.

1. Tree planting. The planting of trees to provide shade from the hot summer sun and a barrier against cold winter winds was one of the first efforts in modifying Nebraska's weather. These readily recognized benefits, prerequisite to establishing homestead claims, continue today. In contrast with states to the east, there are many more trees in Nebraska now than when pioneers first entered the territory.

2. Soil and water conservation. Contour farming, terracing, strip cropping, summer fallow, tree windbreaks, stubble mulching, farm ponds and deferred grazing are among the many maggement practices adapted by Nebraskans following the drought, dust and depression of the "dirty thirties". Like tree planting, these practices were sponsored by government, but carried out by individual farmers. They also are in great evidence throughout Nebraska today.

3. Irrigation. Water resource development has had a tremendous effect on our agriculture. Irrigated acreage increased from 282,000 acres in 1930 to 4,783,000 acres in 1974. Two thirds of this acreage is irrigated by wells developed by individual farmers. The effect of this ability to apply supplemental moisture during periods of critical need is dramatically seen by comparing agricultural statistics for corn during two drought years; 1934 and 1974.

	1934	1974
Corn acres harvested	6,700,000	5,600,000
Corn bushels harvested	21,400,000	380,800,000
Corn bushels per acre	3.2	68.0

	Dry land 1974	Irrigated 1974
Corn acres harvested	2,550,000	3,050,000
Corn bushels harvested	66,650,000	341,150,000
Corn bushels per acre	26.1	103.0

Irrigation in 1974 produced 14 times more corn than was grown in 1934 on less than ½ the acres. During last years' drought, irrigated corn yields were 4 times greater than on dry land acres. These programs are, in my opinion, practical and proven examples of weather modification. The list could be extended to include others.

4. Cloud seeding. Moisture deficiencies and periodic drought continue to plague the much larger area of Nebraska farms and ranches that is not irrigated. The possibility of improving these conditions through cloud seeding naturally is of interest. The following are comments relative to cloud seeding in general and in Nebraska specifically.

A. Implications suggested by the possibility of increasing rain or reducing hail by cloud seeding has captured our imaginations.

B. The desire for cloud seeding activity usually is highest in areas naturally deprived of moisture. It becomes particularly strong during periods of drought.

C. It has caused a clamor for action before means of control are a practical reality.

D. In response to this clamor:

a. Numerous federal agencies have become involved in uncoordinated and perhaps even competing activities.

b. Legislators have made special appropriations and instituted other actions in hopes of causing more rain to fall on their states.

c. Private operators have responded to the desire for more rainfall and have conducted seeding operations financed by farmer group sign-up.

5. Nebraska is not involved in cloud seeding. I am not aware of results from any of the above activities that are sufficiently conclusive to convince me to recommend cloud seeding as an operation to increase agricultural production in Nebraska. My colleagues at the Institute of Agriculture and Natural Resources are of the same opinion.

6. I wish to emphasize, however, Nebraska's interest in research and in all forms of weather modification. Cloud seeding as a research activity certainly should continue. The complexity, the scope, the uncertainties and the costs of cloud seeding and the possible widespread application of results from a limited number of experimental sites are among the reasons why this type of weather modification should be through well planned and coordinated federal and regional projects rather than individual state efforts.

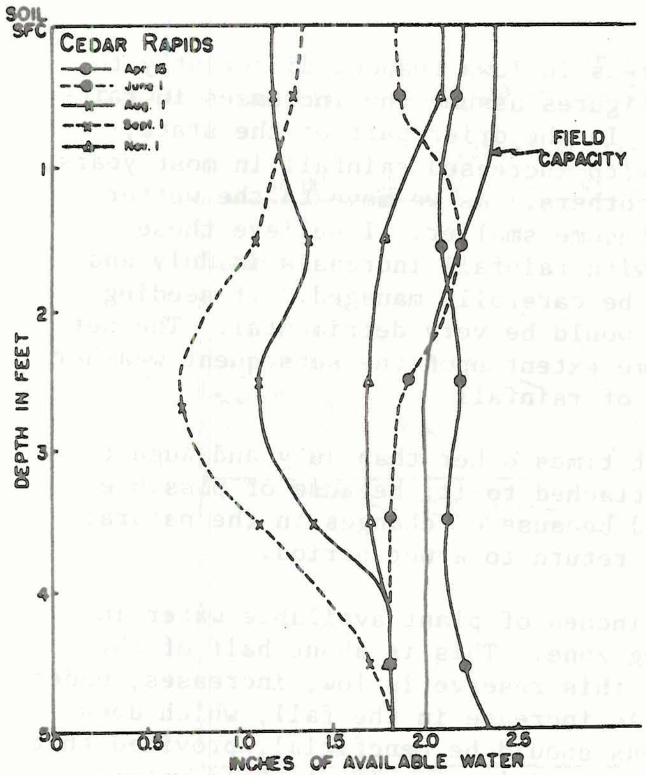


Fig. 3. Cedar Rapids soil-moisture profiles at selected dates. (After Shaw, et al., 1972)

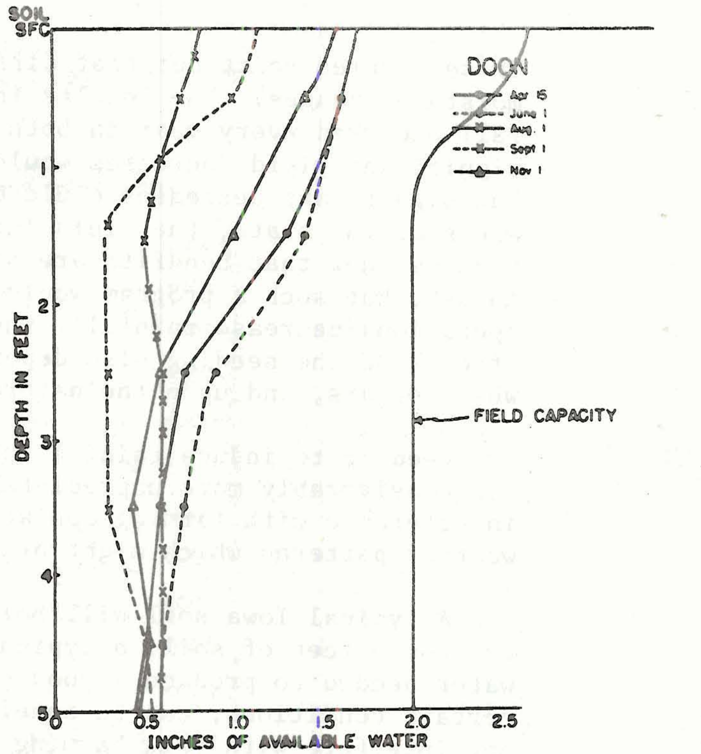


Fig. 4. Doon soil-moisture profiles at selected dates. (After Shaw et al., 1972)

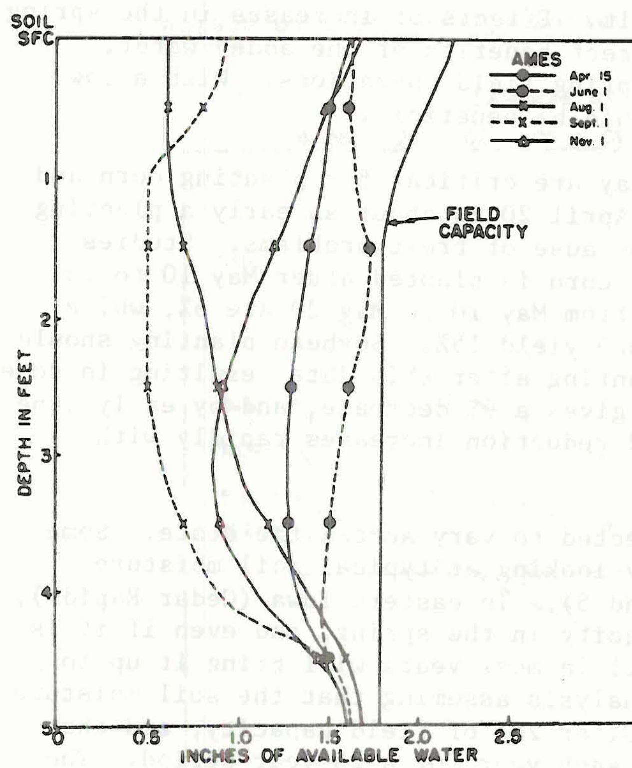


Fig. 5. Ames soil-moisture profiles at selected dates. (After Shaw et al., 1972)

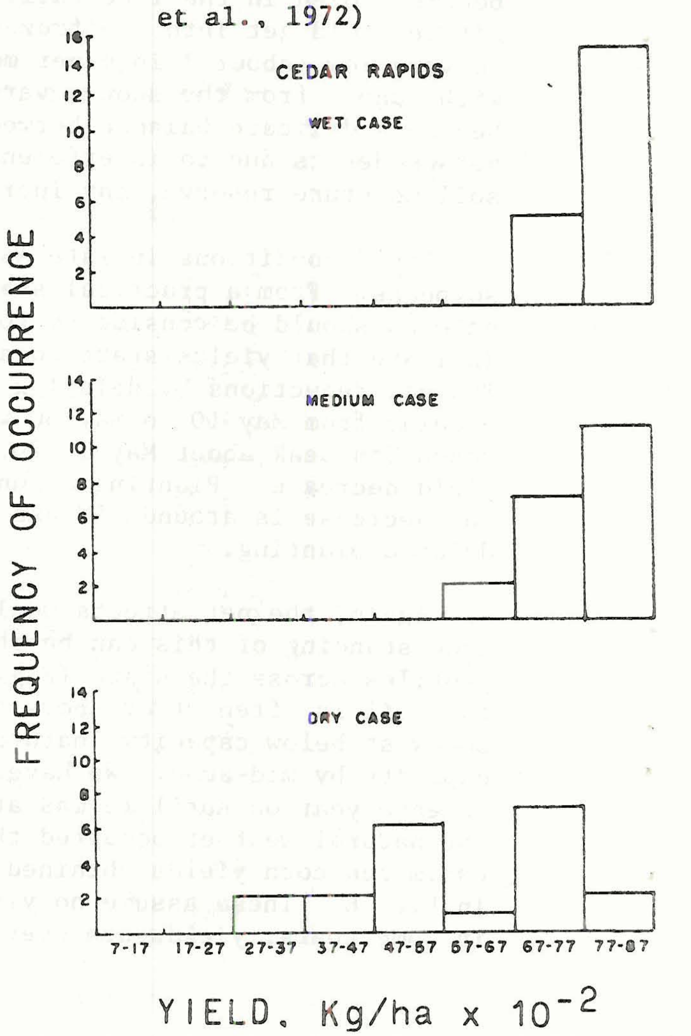


Fig. 6. Distribution of corn yields predicted from moisture stress regression equation, 1951 to 1970.

case. To me this would indicate that seeding should probably be considered in this area, only if the April 15 moisture were below 60% available.

At Doon, in extreme northwest Iowa, the driest part of the state, the situation is normally quite different. Soil moisture rarely reaches field capacity under natural conditions and the difference between an assumed 100% start and 60% start on April 15 are quite large (Fig. 7). At Ames, in central

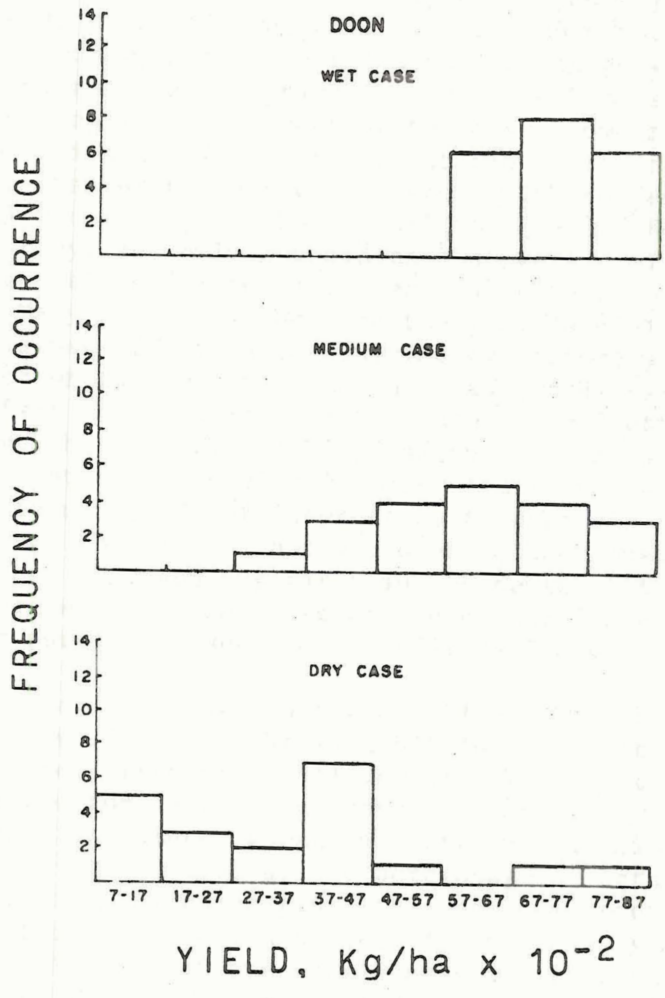


Figure 7. Distribution of corn yields predicted from moisture stress regression equation, 1951-70. (After Zanzalari and Shaw, 1974)

Iowa, the results are somewhat intermediate but would indicate to me that seeding should probably be done only for a low soil moisture situation. Once the crops are in, and if the moisture is still low, seeding operations would have a better chance of being economically beneficial.

The next one is that variable costs to fixed costs are very high ratio and this is an advantage. It is a particular advantage when you contrast it with other methods of water resource management such as dam building which involves long lead times, tremendous investments, a fixed plant that sits there and you can't get rid of it even if you wanted to short of blowing the thing up. Weather modification, on the other hand is a very fast response thing. Joanne mentioned fire fighting and I think this particular economic characteristic of weather modification makes it ideal for that providing that it is physically effective.

High ratio of evaluation costs to operating costs and this means that a lot of programs are just not going to put up the money to do a good evaluation. We have all seen that. A lot of marginal programs are going to exist because it is very expensive to evaluate properly.

Visible apparatus. We all know what that means. The planes are flying around. The radar's working. All these things are very visible. This is good because it means that politicians even if they want to can't keep the thing a secret from the public. On the other hand, there may be cases where it is politically possible to appeal to weather modification in a crisis situation simply to show the public that you are doing something. Whether it is good, bad, or indifferent, you are doing something. And I think that is something that has to be watched.

Next one is that weather modification will not be able in the foreseeable future to eliminate risk to the individual farmer. And that implies that a successful program is going to have to operate on the long run I think on a basis something like the low belt tobacco farmer's cooperative where you combine insurance with modification. So that the guy who still gets wiped out inspite of the fact that modification reduced the mean level of damage is going to be supportive of the program.

Next thing it exploits a common property resource and that implies a large potential for conflict, for over utilization and so forth. We are in the robbing Peter to pay Paul thing here. And the fact that while seven states have statutes that lay claim to all the water above their borders, that it is their cloud, nobody has been able to figure out how to operationally implement that law.

Next one potentially large external effects which imply that people have to get together in order to keep an operational program going. It is expensive to get together and to agree and the private market is not going to be able to handle this.

And the last one, reversability of environmental effect and that of course is a big advantage. I think most of us here would agree. It is hard to see where you are going to do any permanent damage to the ecology once you shut off a cloud seeding program. It may take a little while for the synoptic scale events to go back to where they were before, but very few of us would expect that they wouldn't return to previously normal conditions. And with respect to environmental damage, I agree with those preceeding me who said that this needs more attention. I want to remind you that we should be humble about the fact that our advanced technology proud as we are of it, has not benefitted everybody in this society.

V-23. CHARLES HOSLER*, DEAN, COLLEGE OF EARTH & MIN. RESOURCES, PENNSYLVANIA STATE UNIVERSITY

The obvious advantages of precipitation control, if it can be managed in a predictable manner, will undoubtedly be well covered by other participants. I would, therefore, like to mention a few other areas of weather and climate control not as frequently discussed but of perhaps equal importance.

Plants grow in a microclimate which in part they themselves control. The microclimate not only controls environmental factors affecting production such as temperature, and hence growth, but it also controls the development of plant disease and insects. Efforts have been made to determine to what extent manipulation of the microclimate by controlled grazing, combinations of pasture grasses, etc., might be used to control pests and disease. I am not aware, however, that this has received the attention which might be deserved in agriculture in general. Perhaps agricultural participants can elaborate on this point. Factors such as spacing of crops or combination of crops have effects not only on conditions which bear upon disease or parasites but also upon the extremes of temperature, humidity, stress due to evapotranspiration, etc. which directly affect plant development or survival. The effect of an early or late frost or freeze may well be significantly changed by such microclimatic manipulation. Growing seasons might be extended by some better knowledge of the degree of manipulation of plant temperatures possible and what this would do in a given climate. Modification of the microclimate would appear to deserve intense investigation.

Also, control of cloudiness both day and night to effect temperature extremes is not beyond reason. A day or two of sunshine on a vineyard in September, achieved by dissipating stratocumulus clouds which occur in a cold outbreak in fall could enhance sugar production in the grapes.

Agricultural and forest hydrologists are well aware of the effect of crop density, spacing and character on water retention in the soil.

Some time ago I proposed a method of water storage which has yet to be tried. In the northern tier of states and in higher elevations, it would be possible to spray water in the winter time over a large area to produce a layer of ice up to several hundred feet thick. In this way, without building a containment structure, large quantities of water can be stored and would automatically be slowly released during the hottest period of the year. This presumes that water is available in winter which would otherwise run off and be lost to the region and that unused land is available for storage. During years of abundant water in winter, enough water can be stored to last beyond the next summer. The same ice can be used for cooling the circulating water from a power plant, if desired, and then the melt used for irrigation. I have done calculations on the feasibility of this and it would seem to be quite a reasonable enterprise although it is perhaps too unconventional for most people to take seriously.

V-24. BRUCE CURRY*, DEPT. OF AGRICULTURAL ENGINEERING, OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER

So many things have already been said that I just have a point or two. Things that may have been already said but are worth reiterating.

Being in Ohio and in the eastern portion I am downwind of much of the activity which has been discussed here. That is of considerable concern to us. That is the first point.

The second is that we do already a lot of weather modification in the humid area as we manage our crop systems. We don't call it weather modification, we call it environmental control.

Thirdly, I would like to urge us, as we are considering the different aspects here, to talk not only of the economic aspects and benefits but also to consider that in this day and age we must consider also the energy efficiency. I've heard very little said today about energy efficiency of various weather modification techniques.

As we move to the east in this discussion, we have more people, a more populous area. Thus, we have more heterogeneousness in terms of activity in both agricultural and non-agricultural sectors. Therefore, the interactions of weather modification with man's activities becomes more complex. The point was fairly well said a little bit ago. The situation is simpler for a mono-culture. In Ohio we have anything but a mono-culture.

My last point is that I hope that simulation techniques will be emphasized as a tool for any research proposed. I think such techniques are coming of age and have a significant role to play as a tool in such research programs.

V-25. JUANITO RAMIREZ*, PROFESSOR, SOILS SCIENCE, UNIVERSITY OF NORTH DAKOTA

A dozen years ago four southwest North Dakota counties and then 7 elected to form weather modification associations and those associations hired some party and then parties to attempt to reduce hail damage and then to increase rainfall through cloud seeding. About four years ago the Bureau of Reclamation supported a study by an interdisciplinary team at North Dakota State which was aimed to come up with a quick and dirty estimate of the impact of weather modification upon the economy of the state which is basically agriculture. Now this study after three years basically showed that an additional inch of growing season rainfall was best. An additional inch of water in the state of North Dakota, rainfall or otherwise converts, to about 2-1/2 bushels of wheat, or about 100-150 lbs. of hay per acre. The economists, the agricultural economists in our project, even went as far as converting the figure to $300,000,000 per inch of additional water, in that report we said that additional growing season rainfall. One thing was quite intersting at the time this report came out. The irrigation equipment suppliers in the state us-d our report and said let us get you the additional inch of rain that converts to $300,000,000/year. You should see the advertisements in some of the farm magazines.

In my mind, the most significant consequence in this study for the Bureau was the development of a statewide public educational program on the technology of weather modification and on the probably impact that it could have in the state, which was rather successful. This public educational program was rather successful. We were invited to go out into town meetings and tell them about how weather modification is done. And then the agricultural economists, who were quick to follow, that this would mean an additional 2-1/2 bushels of wheat per acre. It is not surprising that after a full summer of town meetings, press clippings, unsolicited tv and radio interviews, almost twenty of the 53 counties in the state have either a weather modification association or something else which were prepared to hire someone to seed some clouds. We made sure that in thes these town meetings, we pointed out the controversies, the uncertainties, that still exist but the farmer very understandably took it this way. Even a 30% chance of success 2-1/2 bu/acre of benefit against a dime per acre cost is too much to ignore. Furthermore, earlier this year, our state legislators passed a bill which basically pledges financial support on a matching basis to counties which decide to have an operational program, overseen by a state weather modification board which is also created by the bill.

So much has been said about world food supply and weather modification, so much has been said abour research and weather modification in North Dakota, so much has been said about the big items. Let me come to the trivial items that I was referring to. Let me stress it this way. Let me recreate a conversation I had with a couple of farmers where there was an approved weather modification program. This farmer on behalf of other farmers in the county offered us, the University, $3,000 to evaluate for them whether or not the program is working. It was most difficult to tell him that the money was insufficient. We came up with an alibi. So then he said, well if you cannot do it, how about the state? How about the federal government? How about a national program of evaluation of these things that are now going on? And I said, "Yeah, how about that?"

CHAMP TANNER*, SOILS DEPARTMENT, UNIVERSITY OF WISCONSIN

When it comes to the weather or the environment of plants, I think we all agree that temperature and water are of major importance. Radiation has been mentioned today and it has direct effects on photosynthesis and indirect effects on evaporation or transpiration, but as Bob Shaw was pointing out, there is ample evidence accumulating that in terms of photosynthesis, right now the plants we have are really not using their full photosynthetic capacity anyway. Often this is because of temperature and water limitations. Actually in terms of types of modification such as irrigation or precipitation modification, or canopy micro-climate modification, water appears to be the easier to modify. We either have too much or too little most of the time. It is the too little part which really influences yield because if we get too little it does prevent the CO_2 uptake and without that you don't get any production. But there are other things that come on at water deficiencies within the plant much earlier than that which stops photosynthesis, and which also influence growth in some crops; not all, but some. We need to learn more about these processes within the crops to really say what water will do.

F. H. King, the first agricultural physicist in the U. S. at the turn of the century, pointed out at that time that it was rare in the humid regions that there was land or crops in any year that did not suffer from a deficiency of water to reduce yields in some way, to some extent. It would be very rare if this were not true. He recommended supplemental irrigation instead of weather modification, but he was at it way back in the time when that was heretical to think of supplemental irrigation. Here in Colorado two gentlemen by the names of Briggs and Schantz very early, though it was incomplete, gave the starting clue as to how water related to yield. Their work has been updated a little bit, but it is kind of humbling to see how little we have come since those two or three early men. At the same time, I do want to say that an extension of Briggs's and Schantz's work does show a very interesting thing and this is the one point I would really like to make to you today. That is that when you are talking about modification, when you go in the humid regions and the sub-humid, you get far more out of an inch of water than you do here in arid regions. It is a better inch of water when you get it in humid regions, and there is already a lot of water to irrigate with when you are deficient of water. This is something that people simply do not seem to keep in mind very often about water. So if I were to talk about the economy of irrigation or weather modification, I would say go East young man, go East!

V-27 Agricultural Applications for Weather Modification

James G. Ross, South Dakota State University

Historically the chief limiting factor for crop production in South Dakota has been available moisture. Consequently, there was an early interest in the application of cloud seeding technology ever since Langmiur and Schaefer first demonstrated an ability to modify clouds. Preliminary researches aimed at exploring this technology were carried out at South Dakota State University in the 1950's. Intensified researches at the Institute of Atmospheric Sciences after its establishment in 1959 have applied modern techniques to the problems. Schleusener (Dennis et al., 1974) indicated that the objectives of the institute were the development of means to increase rainfall and suppress hail in the northern Great Plains region and to assist in the development of operational projects. These objectives were pursued through theoretical and laboratory studies as well as randomized field experiments.

The following is taken directly from the final report under contract no. 14-06-D-6796 (Bureau of Reclamation) made by Dennis et al. (1974).

"INTRODUCTION AND SUMMARY OF ACCOMPLISHMENTS

1.1 Overview of Precipitation Management Concepts

Much of the growing season rainfall in the northern Great Plains falls from cumulus and cumulonimbus clouds, which occur either individually or in organized groups (Fig 1.1a). The precipitation efficiency of these clouds is often small, meaning that only a small fraction of the condensed water falls to the ground as precipitation. The remainder is lost by evaporation around the edges of the cloud or blown downwind in the form of a large anvil cloud shearing off from the cloud top.

Nearly all of the precipitation which reaches the ground in the summer over the northern Great Plains is formed by the accretion process, in which large particles falling within a cloud sweep up the smaller cloud droplets. The falling particles are called precipitation embryos. Some embryos are liquid droplets formed around unusually large cloud condensation nuclei or by chance collisions among ordinary cloud droplets; others are ice particles formed as the result of condensational growth around ice nuclei or frozen cloud droplets.

One of the simplest concepts of cloud seeding is the introduction of artificial embryos to hasten the formation of precipitation in new cloud towers. The artificial embryos may be large hygroscopic particles (Fig. 1.1b) or ice particles formed around artificial ice nuclei, such as silver iodide crystals (Fig. 1.1c). The commercial seeding programs in the Great Plains in the 1950's generally involved silver iodide seeding from ground generators with a view toward production of artifical frozen precipitation embryos.

Cloud seeding techniques have also been used in attempts to suppress hail. The concepts involved here are that:

1. Glaciation of the cloud water will reduce liquid water concentrations in supercooled regions, thereby slowing the hailstone growth rates; and
2. Some of the frozen particles become additional competing hailstone embryos. Assuming that the total supply of supercooled water available in a cloud is fixed and is a limiting factor in determining final hailstone size, this effect could reduce hailstone size.

Evolving understanding of the dynamics of cumulus clouds and of the microphysical processes within them over the last 20 years has shown that the total rainfall production from a convective cloud depends upon many interacting factors, notably, the cloud's size. At the same time, evidence has been

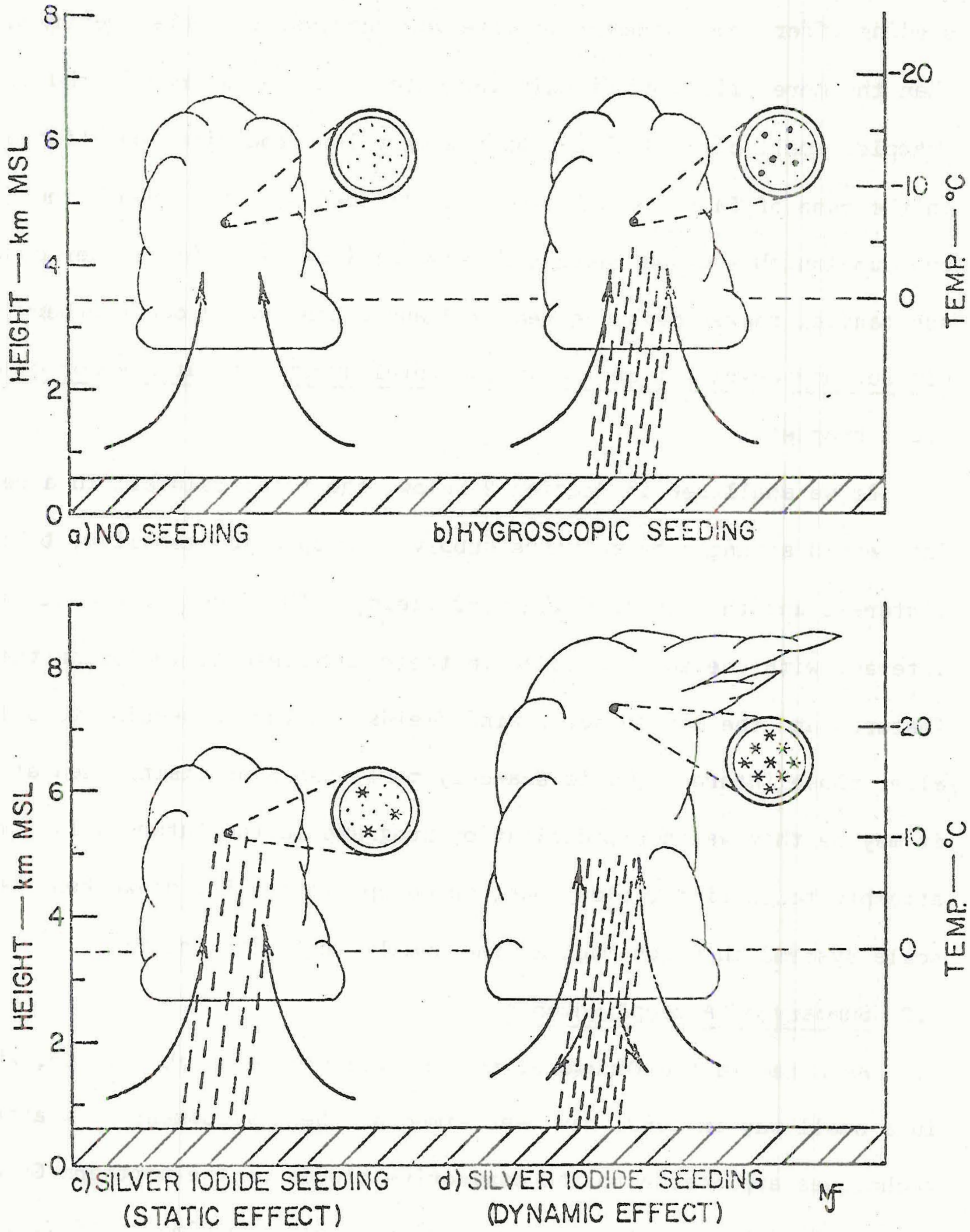


Fig. 1.1 Elementary seeding concepts applied to typical cumulus cloud of the northern Great Plains.

accumulating that seeding can affect not only the precipitation formation processes but also the cloud dynamics (Fig. 1.1d). The concept of dynamic seeding offers much greater promise for successful weather modification programs than the mere "milking" of existing water supplies stored in the clouds. For example, small cumulus clouds have a very low precipitation efficiency, zero in the case of fair weather cumulus. If seeding could induce the growth of one cumulonimbus cloud instead of several isolated fair-weather cumulus, a substantial shower might be realized where none would occur otherwise and <u>without any overall increase in the total amount of water vapor condensed</u> into cloud droplets.

As we shall see in Section 2 below, the total rainfall in a region is influenced strongly by moisture supply, atmospheric stability, topographic features, and the larger scale wind fields. The developing cumulus clouds interact with one another and with their environment, including the topographic features and the larger scale wind fields. Although seeding to deliberately alter those interactions is scarcely more than a promising idea at this time, it may be that weather modification programs in the future will involve deliberate attempts to initiate, slow down, speed up, intensify, or weaken the larger scale systems in which much of the cumulus activity occurs.

1.2 Summary of Accomplishments

As noted in the Foreword, the Institute's research program, which began in a small way in 1962, has been aimed at the development of weather modification techniques applicable to the convective clouds of the northern Great Plains. The results obtained from our randomized field experiments (Fig. 1.2) supported by numerical cloud modeling studies and laboratory studies of seeding agents have established the reality of the basic concepts of precipitation management mentioned in Section 1.1. This is not to say that the concepts are applicable

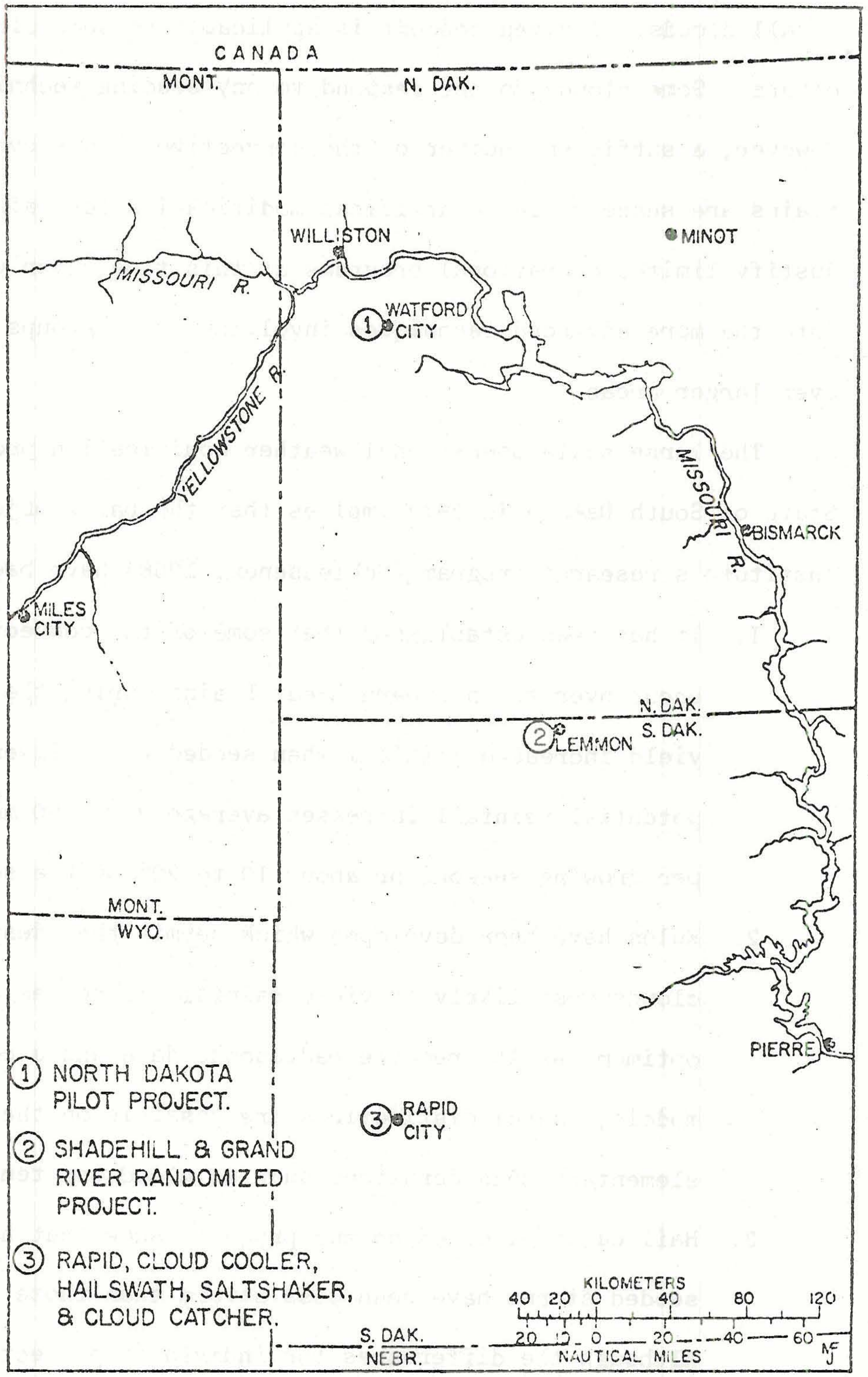


Fig. 1.2 Locations of randomized field experiments conducted by the Institute under Project Skywater.

in all clouds. A given concept is applicable to some clouds and not to others. Some clouds do not respond to any seeding techniques used so far. However, a sufficient number of the convective clouds over the northern Great Plains are susceptible to artifical modification for rainfall stimulation to justify limited operational programs at this time, even while research continues into the more advanced techniques involving cloud groups and systems extending over larger areas.

The large scale operational weather modification program started by the State of South Dakota in 1972 implies that the basic objectives of the Institute's research program (Schleusener, 1966) have been reached. Specifically,

1. It has been established that some of the convective clouds which occur over the northern Great Plains during the summer months yield increased rainfall when seeded with silver iodide. The potential rainfall increases average 25 to 50 mm (1 to 2 inches) per growing season, or about 10 to 20% of the seasonal normal.
2. Rules have been developed which permit the identification of those clouds most likely to yield rainfall increases from seeding. While optimum results require radiosonde data and a compute to run cloud models, useful distinctions are possible on the basis of more elementary considerations such as cloud top temperatures.
3. Hail data collected on our projects show that hailfalls from seeded storms have been less severe than those from unseeded storms. Although the differences for individual projects are of marginal statistical significance, at best, the consistency of results over many project seasons suggests some physical effect.
4. Burning a solution of silver iodide and ammonium iodide in acetone generators on aircraft operating in updrafts below cloud base has

been shown to be a good and economical method of delivering ice nuclei to convective clouds.

5. The results of our research experiments using silver iodide as a seeding agent were communicated to the South Dakota Weather Modification Commission and to agencies of the states of North Dakota, Montana, Nebraska, and Kansas. On the basis of these results and on the assumption that they could be extrapolated to larger areas, the State of South Dakota embarked on an operational seeding program in 1972 which has now been enlarged to cover about two-thirds of the State's 67 counties. Weather Modification Authorities have been set up to cover 22 of North Dakota's 45 counties, and seeding operations are being conducted in many of those counties.

The attainment of our basic objectives was made possible through field experiments supported by laboratory testing of seeding materials and by cloud modeling studies. In addition to the five items listed above, the following research accomplishments can be noted:

6. Quantitative weather radar data systems incorporating on-line minicomputers have been designed, built, and operated. Their value in the conduct and evaluation of field experiments has been demonstrated. Judging from our studies of rainfall-radar relationships, such systems could be used to monitor rainfall over large areas in real time.

7. Although not yet proven as an operational tool, seeding with a hygroscopic agent (common salt) has been shown to have promise in treating cumulus clouds.

8. The superiority of solutions of silver iodide and ammonium iodide in acetone as compared to previously used solutions has been established by wind tunnel/cloud chamber tests. The silver iodide-ammonium iodide solutions have been used on field experiments with satisfactory results. A quality control program has led to guidelines for increased effectiveness of silver iodide generator operation in field programs.

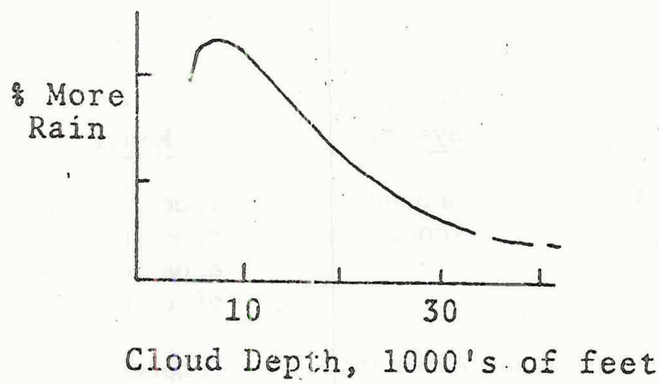
9. Numerical cloud models have been used in the conduct and evaluation of field experiments. Randomized experiments which would otherwise have been judged inconclusive have yielded strong indications of seeding effects when analyzed with the aid of the models. Simulations of seeding treatments have been included in cloud models and help to explain certain observations of seeded clouds."

The technical ability available for application of weather modification technology was summarized by Schock _et al_. 1974. This summary of their methods of evaluations and results are indicated below.

"Summary of Technical Ability

The effects of seeding for rain increase and hail reduction vary with cloud size. As the cloud size becomes bigger, the technology is less capable of modifying it. Overall benefits for a season which the cloud seeding technology can provide depend on the variable weather of the season. General results from research projects are given below.

Rain Increase

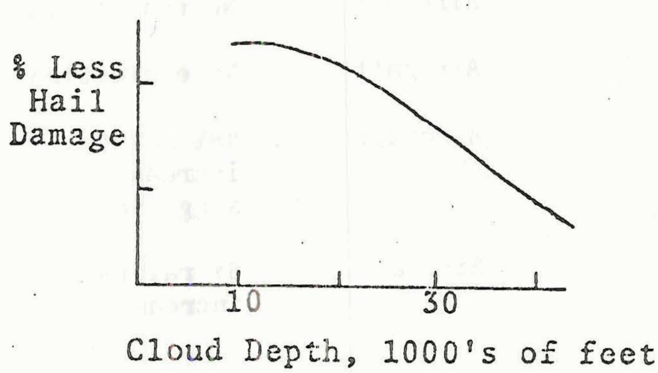


Clouds of depths greater than 10,000 feet rain naturally; thus, the effect is to help the clouds produce more rain. The best results are achieved on the smaller clouds.

Overall benefit is 10-20% rainfall increase.

A 10% increase in rainfall from cloud seeding amounts to an additional 0.60 inches for dry years and 1.2 inches during a normal rainfall season.

Hail Damage Reduction



Seeding reduces the sizes of hailstones but cannot reduce winds from storms. Winds contribute significantly to hail damage.

Overall benefit is 30-60% less hail damage.

South Dakota's Results

Weather modification for increasing rainfall and reducing hail damage has been conducted actively in South Dakota since 1951. Most of these projects were not adequately funded so complete evaluations were not conducted. When available, results have been indicated. The table below summarizes activity from 1951.

Date	Area Seeded	Delivery Systems	Results
1951-1954	Portions or all of 28 counties.	Ground generators	Inconclusive due to inadequate number of cases
1957-1958	Black Hills and Brookings	Aircraft	Inconclusive due to inadequate number of cases
1961-1964	Fall River, Custer and Pennington	Aircraft	No evaluation
1965-1970	Fall River, Custer and Pennington	Aircraft	7% rainfall increase
1968-1969	Miner	Aircraft	No evaluation
1968	Brule, Buffalo	Aircraft	No evaluation
1970-1971	Brule, Buffalo, Lyman and Gregory	Aircraft	48% rainfall increase suggested
1971	Perkins, Corson	Aircraft	8% rainfall increase

All projects which were evaluated for hail damage reduction did not show any large effects because several seasons of data are necessary. A study has shown that 5 or more seasons of data are necessary to properly evaluate operational programs.

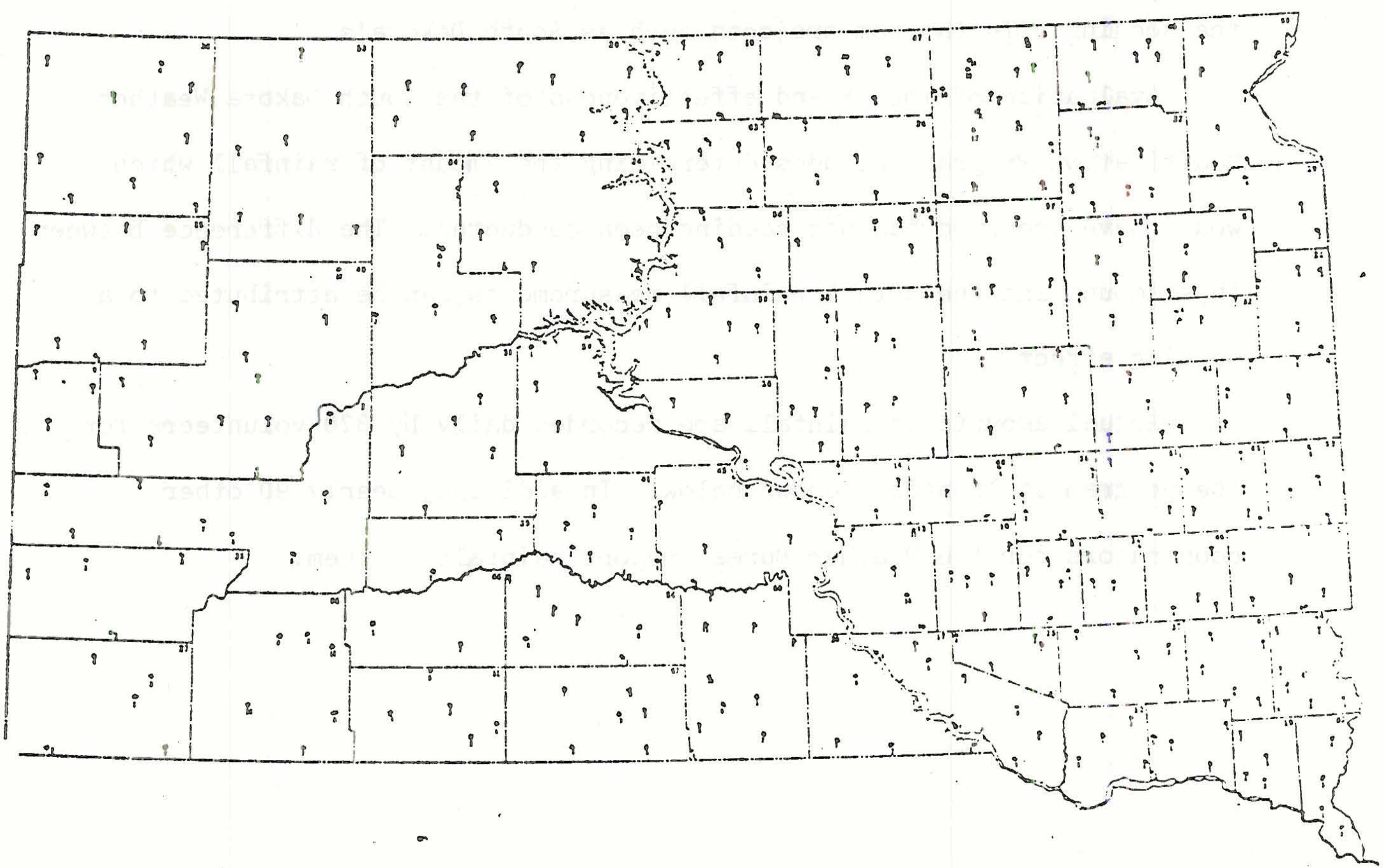
The technology's ability to increase rainfall and decrease hail damage has been demonstrated by the research projects. Based on these research results the DWM has proceeded, accordingly, to utilize this technology in conducting the cloud seeding program.

Evaluation of the effect of the South Dakota Weather Modification Program on rainfall and hail damage is undertaken to determine how well this technology is being applied, not to prove that weather modification works. Five or more years of operations are necessary to determine reliably the seeding effects from projects such as South Dakota's.

Evaluation of impact and effectiveness of the South Dakota Weather Modification Program includes determining the amount of rainfall which would have occurred had not seeding been conducted. The difference between this amount and the actual rainfall measurements can be attributed to a seeding effect.

Actual amounts of rainfall are recorded daily by 370 volunteers for the program at locations shown below. In addition, nearly 90 other cooperators for the Weather Bureau report rainfall to them.

DWM RAINGAGE NETWORK



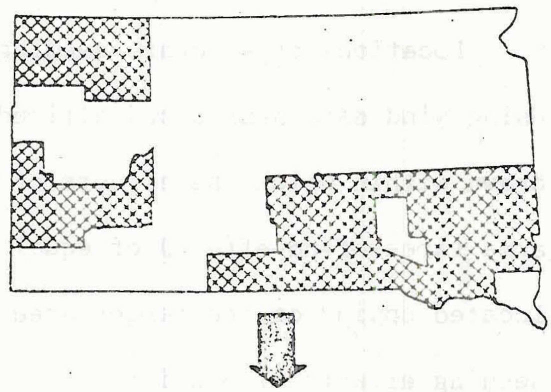
Participating Areas

The South Dakota Weather Modification Program began in 1972 and has been conducted during the months of May, June, July, and August each year since. Both hail suppression and rain increase activities were conducted over those counties shown on the maps below.

1972

26 Counties

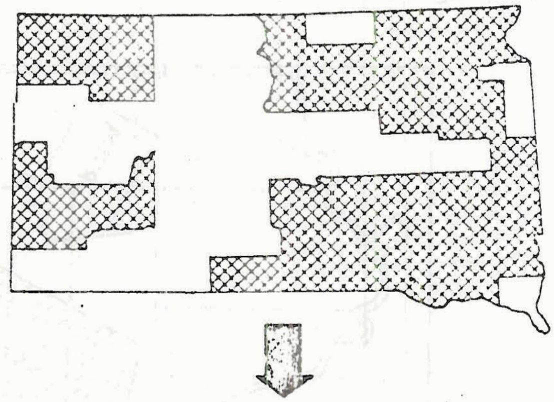
17,181,000 Acres



1973

42 Counties

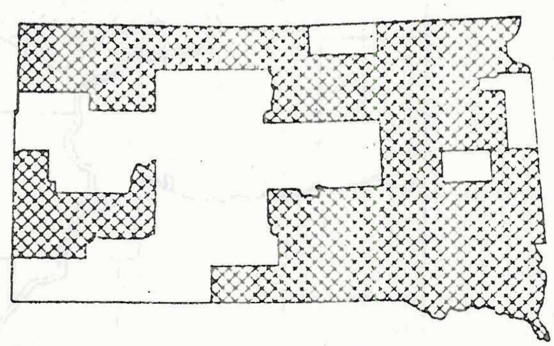
26,612,000 Acres



1974

46 Counties

29,547,000 Acres

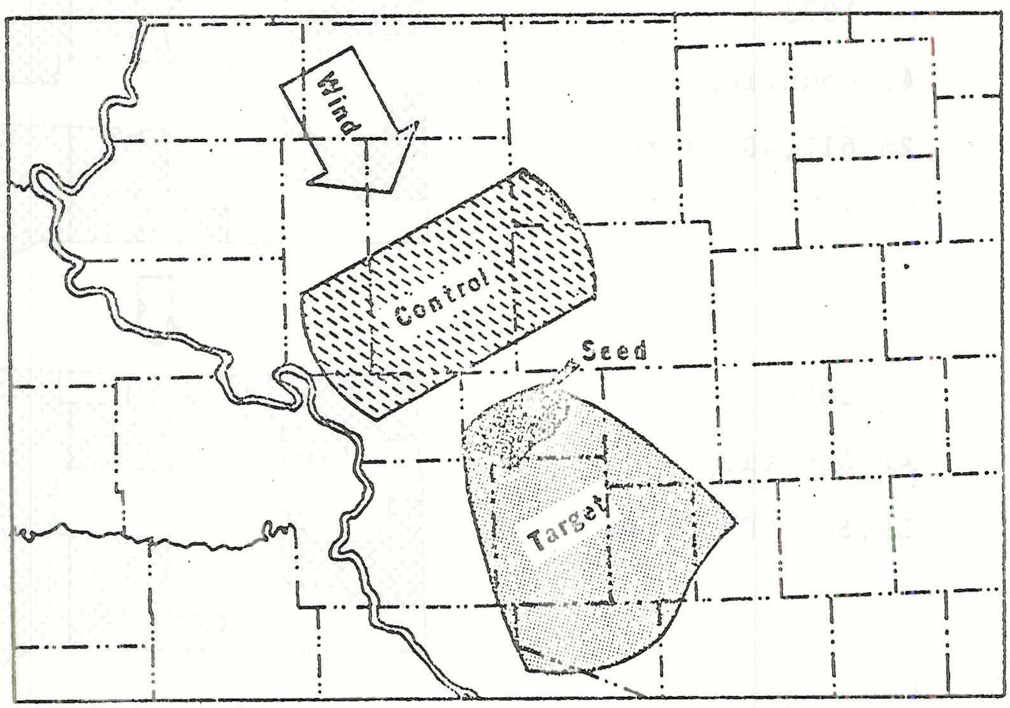


Evaluation Procedures

Since the beginning of the state sponsored program in 1972, two evaluation techniques have been used to determine the effectiveness of rain increase efforts. These techniques, termed "area-of-effect" and "target-control", are briefly described below.

Area-of-Effect

Locations of aircraft seeding are plotted on a map of South Dakota. Using wind data near cloud altitudes, a target area (area-of-effect) is drawn within which the effects of seeding should have occurred. A control area (area-of-no-effect) of equal size is drawn nearby. It is generally located upwind of the target area in order to eliminate any possibility of seeding effects within it.



Then the rainfall observations in the target and control areas are tallied and the results compared with the following restrictions:

1. The control area must be at least 100 miles downwind of any other seeded area to insure control purity.
2. Both the control and target area must have experienced precipitation on the day of seeding. This reduces the possibility of differing cloud conditions in the two areas influencing the evaluation.

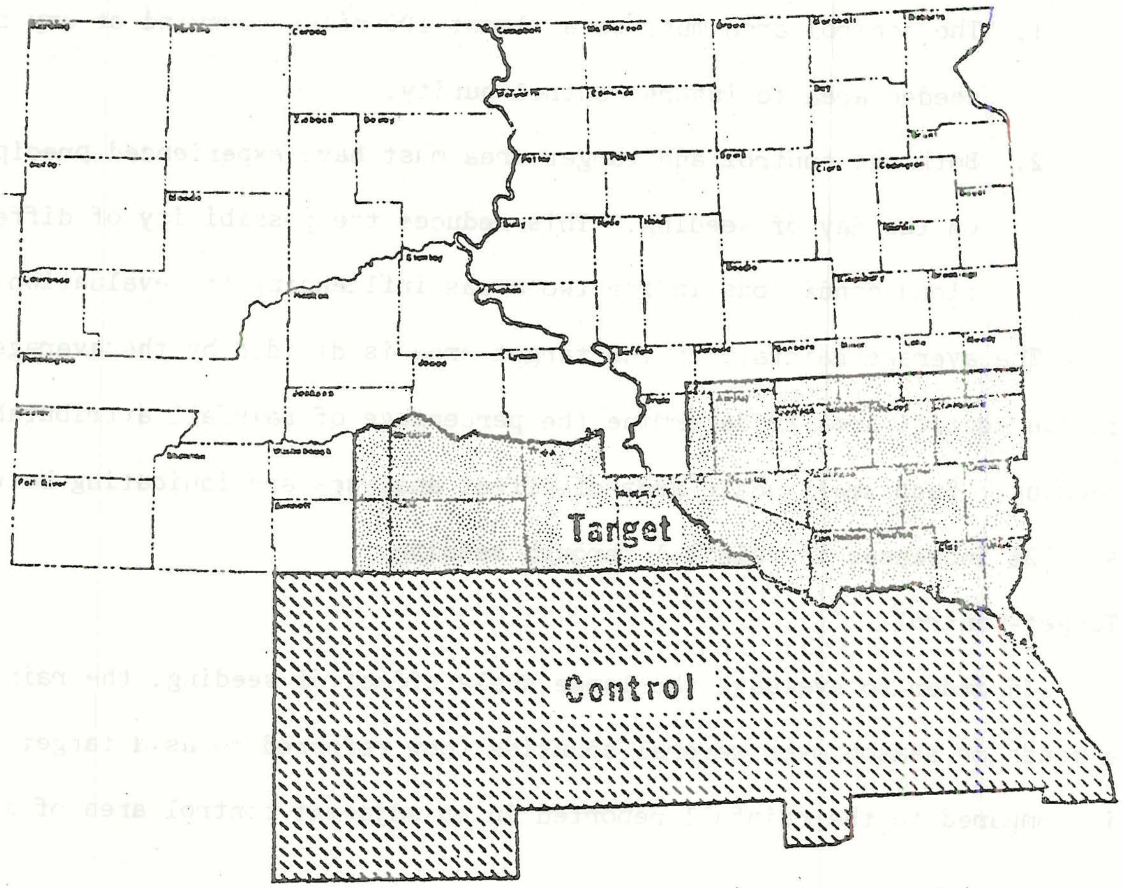
The average rainfall in the target area is divided by the average rainfall in the control area to determine the percentage of rainfall attributable to seeding. Such small scale area-of-effect analyses are indicating between 18 and 22% increases in rainfall through seeding.

Target-Control

In order to evaluate the large scale effect of seeding, the rainfall for a month or season over several counties (now referred to as a target area) is compared to the rainfall reported in an adjacent control area of similar size.

First, the average or normal rainfall over a 30 year period is obtained for each area. The ratio of these normals indicates how much more rainfall one area typically receives.

Then the rainfall for the seeded period is determined for each area. The ratio of these amounts is adjusted for the climatological difference by dividing through by the normal target-control ratio. Were there no seeding effect, the ratio should be 1.00. The difference between 1.00 and the calculated ratio, multiplied by 100 is the percentage of rainfall attributable to seeding.



These large-scale analyses are indicating about 10% more rainfall than would have occurred without seeding.

These large-scale analyses are indicating about 10% more rainfall than would have occurred without seeding.

Results of the

South Dakota Weather Modification Program

Evaluation Period	Type Evaluation	Scale	Results
May - August, 1972	Rain Increase (Target/Control)	Small	21% Increase
May - August, 1973	Rain Increase (Area-of-Effect)	Small	22% Increase
May - June, 1974	Rain Increase	Large	* 10% Increase
May - August, 1972	Hail Suppression (Target/Control)	Large	40% Decrease
May - August, 1973	Hail Suppression (Target/Control)	Large	20.5% Decrease
May - Sugust, 1974	Hail Suppression (Target/Control)	Large	No Data Available Until January, 1975.

* Evaluation not completed. Preliminary indications of 10% for large area evaluations."

A decrease of 18% hail damage for hail depression 1974 was later estimated by Schock et al. (1975).

The effect of additional precipitation during the growing season was studied by a study team at South Dakota State University. The following is taken from the summary of the final report for contract 14-06-D-7158 with the Bureau of Reclamation.

"Yield responses to additional rainfall are influenced by the presence or absence of other limiting factors affecting production. Yield responses take the form of a sigmoid curve in which the beginning of the curve gives little or no increase in yield since a certain size of plant is necessary before either seed or forage yield might be obtained. The steeply rising part of the curve is situated where factors affecting growth are abundantly available. As one or more of these become limiting, the slope of the curve decreases till no increase in yield results from added increments of water.

It is clear, therefore, that any increase in production as a result of an added increment of rainfall is dependent upon the part of the curve where the increase occurs. For example, alfalfa yields at Redfield in 1951 increased 921 lbs. per acre for each inch of added water up to five inches at which point no further increase occurred. In 1952 in the same experiment a warmer season occurred so temperature was not a limiting factor so quickly. Each inch of irrigation up to five inches increased yields 1,685 lbs. per acre, and from 5 to 14 inches the increase was 160 lbs. The use of linear regression coefficients tends to underestimate the yield increases at the middle increment and overestimate them at the lower and higher increments. The optimizing of factors influencing production will tend to extend the steep part of the curve and make the linear regression coefficient approximate this slope.

Another example of the effect of limiting factors on production was shown in the yield of Chris spring wheat on the Poinsett-Kranzburg silty prairie soil association occurring in northeastern South Dakota. An increase of 5.26

bushels/acre was observed for each of added rainfall for 10 plot years on the three experiment farms in this area, but when 11 commercial farms were added, an increase of only 1.75 bushels/acre was noted. The factors limiting production (weeds, insufficient preseasonal soil moisture, and lack of fertility) had caused the curve to flatten out, and the linear regression line reflected this occurrence. In eastern South Dakota disease on spring wheat caused a negative effect with one inch of rainfall, -0.66 bushels/acre per inch at the experiment station at Brookings. A difference in response between different soil associations was also found when experimental plots were placed on farmers' yields. In the central region of South Dakota using six plot years on the Glenham Glacial Plain, unfertilized spring wheat yields were 1.55 bushels/acre/inch of rainfall while the fertilizer yield increase was 2.44 bushels/acre. Protein decreased slightly less on the fertilizer (0.09 percent) than on the unfertilized (0.10 percent) spring wheat for each inch of added rainfall.

In western South Dakota, an opportunity to study the effects of precipitation, temperatures throughout the growing season and soil moisture at time of seeding on yield of spring wheat was afforded from data collected from 1909 to 1936 (108 plot years) at Newell and from similar data collected from 1951 to 1932 (52 plot years) at Ardmore. Using simple regression of yield on available moisture at Newell, including soil moisture at planting and rainfall during the growing season, one inch of increased rainfall would give 3.1 bushels/acre increased yield. When the various factors were broken down into six variables, one inch of additional June precipitation could be expected to add 3.1 bu./ac. and July rainfall, 1.57. For every one-degree ris in July temperature a decrease of 0.03 bu./ac. may be expected, while an increase of 0.54 for each degree of April temperature may be expected. For every inch of soil moisture at planting, 2.54 bushels/acre may be anticipated. These six factors comprise 68 percent of the variation as indicated by the multiple correlation coefficient.

The data collected at Ardmore on spring wheat have 91 percent of the variability accounted for by six variables. The regression line is curvilinear and represents part of a sigmoid-type curve so response to rainfall varies according to location on the curve. If June rainfall were increased from one to two inches, 8.58 bushels/acre would be added. An additional inch of soil moisture would add 1.72 bushels/acre, and an inch of additional rainfall above six inches for the season would give an additional 2.78 bushels/acre. Every degree above 85° F. would reduce yield by 0.361 bushel/acre.

An example of the effect of timeliness of rainfall as well as effect of optimum fertility was shown in small grain experiments situated throughout the state. The growing season was divided into the first 9 weeks (from seeding to anthesis) and from 5 days to 69 days before harvest (from late tillering to just before harvest). It was found that the first 9-week period was more importantthan the later period. Soil moisture at time of seeding was also significant in the analysis. At 30 locations one additional inch of soil moisture at planting gave an increase in bushels/acre of 1.66, 3.12, and 2.08 for wheat, oats, and barley, respectively, on the unfertilized plots and 3.70, 6.94, and 4.62 on the fertilized plots. For 52 locations an inch of additional rainfall in the seeding to anthesis period gave an increase in bushels/acre of 1.86, 3.50, and 2.33 for wheat, oats, and barley, respectively, on the unfertilized plots, and 3.49, 7.18, and 4.79 on the fertilized plots. When 90 locations or plot years were included, it was found that a decrease in yield was indicated for July rainfall. For all small grains the decrease in yield for each inch above normal was 97.6 lbs./acre for the unfertilized and

186.3 lbs./acre for the fertilized plots.

For corn the time of additional rainfall is extremely important. In experiments in eastern South Dakota and adjacent Minnesota, seventy-six experiments in six years were studied. It was shown that the effect of an inch of additional rainfall above normal varied from -6.7 bushels/acre between May 15 and 31 to +13.4 during July 15 to 31 and to +12.37 between August 1 and 14. The effect of one inch above normal for July 1 to 21 was an increase of 3.9 bushels/acre, but from July 22 to August 11, the increase was 19.5.

Yields of native range grasses in western and north central South Dakota were measured over a period of 26 years at Cottonwood and 21 years at Eureka, respectively. At Cottonwood annual harvest of mainly western wheatgrass gave an increase of 116 lbs. of forage per inch of rainfall during April to June, while at Eureka in a needle grass dominant association, an increase of 396 lbs. of forage occurred.

The effect of increased rainfall on annual value of crops produced in South Dakota has been studied. At lower levels of rainfall in the northwestern part of the state, increased production ($0.35/acre/inch increase) is less than at the higher rainfall levels in the southeastern area ($3.75/acre/inch increase). Land prices likewise are affected in a nonlinear fashion so a disproportionate increase per inch of rainfall occurs at the higher rainfall levels.

The response of crop yields to added moisture indicated in this report is based upon data collected in the past and does not adequately reflect the effects of increased technology that will most probably be employed in the future. Therefore, the estimates of increased yield response will be found to be conservative for the future unless the application of technology is interfered with through disruption of research and extension programs. If it is possible to maintain moisture increases in the steep part of the sigmoid yield curve refered to in this report, then large increases per inch of increased rainfall can be expected in the future. Such moisture increases point up the necessity for increased emphasis on research and application of findings relative to the limiting factors affecting yield. Otherwise the expense entailed in weather modification cannot be justified.

Changes in livestock production as the result of increases in growing season precipitation are dependent on increases in feed and forage produced. Data presented here suggest forage available for grazing would be increased on the order of 50 pounds per acre per inch of growing season precipitation. This would indicate an average carrying capacity improvement of one additional AUM per 12 acres of range.

For the major feed grain producing areas of eastern South Dakota greatest use of grains for livestock includes corn, oats, barley, and sorghum. Productivity increases for corn suggest that finishing of market animals could increase approximately 1.4 to 4.8 percent for swine and sheep, and 0.2 to 0.5 percent for cattle."

Recommendations for research investments for the future in the weather modification area.

In general, I consider the greatest need is for independent evaluation of the effects of cloud seeding both of past operations that have been carried out in South Dakota and in the future. Any operational plan should have built into it the provision for an evaluation by a separate imported organization. If this is not done, sustained political support cannot be counted on over a long period of years. If possible, actual crop yield increases should be obtained from randomized field plots in seeded and unseeded areas. The actual and potential benefits in economic terms could then be computed.

Specific research needs, for increasing the effectiveness of operations, that have been suggested to me by Martin Schock, Director of the Division of Weather Modification in South Dakota and by Dr. Arnett Dennis, Director of the Institute of Atmospheric Sciences at South Dakota School of Mines and Technology are as follows:

1. About 60% of precipitation occurs from night-time clouds. Specific research has not been done to learn how to best seed these.
2. How can stratiform clouds be induced to increase their rainfall efficiency?
3. How effective is non-growing season precipitation in increasing yields?
4. What are the potential economic benefits for weather modification in dry compared with wet years?
5. Is it possible to increase the distribution of rainfall more favorably throughout the season? What would be the economic benefits of such?
6. In a diverse crop area, what are the economic advantages or disadvantages for weather modification.
7. Does the effect of increasing rainfall have an effect on temperature? Is there a delayed effect?
8. Better methods are necessary in assessing the effects of reducing hail damage.
9. Better methods of communicating results to farmers are necessary. Increased precipitation is only one of the limiting factors for production. All factors must be optinized to realize maximum yields.

10. There is a need for short-time forecasting with a lead time of two hours.

11. More precise statistical techniques are necessary for some evaluation procedures.

12. More information on the best delivery systems is needed.

13. More information on large area effects is necessary including down wind effects.

14. Is it possible to reduce torrential rains such as have caused extensive damage in the Red River valley area near Fargo in 1975.

Summary and Conclusions

Since South Dakota is a land of too little rain, there has been an interest in potentials for increasing moisture ever since the demonstration of cloud modification by Langmuir and Schaefer. Efforts to modify rainfall by means of ground generators were inconclusive during the 1950's and interest in the application of the technology in its state at that time died out. Intensified researches at the Institute of Atmospheric Sciences at Rapid City after 1959 have applied modern techniques to the problem. Success in defining the methods of seeding daytime cumulus clouds for greatest rain efficiency has been achieved. Cloud models have been defined so morning weather data fed into a computer will give the likelihood of seedable clouds occurring that day. This information has been applied by a state funded Division of Weather Modification located at Pierre. A system of weather modification units situated strategically throughout the state provide instant response to opportunities for aerial seeding with silver and ammonium iodide within precise areas of clouds when the radar station indicates opportunities. Local control of whether more rain is needed within the area is provided by locally based elected officials. Each of the areas in the state are in constant communication with the Pierre office, which gathers the weather data from the meteorological service, and feeds it into a computer at Denver to determine by means of the cloud model whether seeding should be made. The radar sites with ancillary aerial cloud seeding facilities determine the actual operations. Their evaluations for 1972-74 of rain increases through "target-control" and "area-of-effect" methods and also large area evaluations have indicated increases of 10% to 22% rain increase. Hail suppression decreases from 18% to 40% were calculated.

What increased precipitation of these proportions would mean to the state of South Dakota was determined by a study team from South Dakota State University. It was shown that the effectiveness of increased precipitation was directly proportional to the removal of other limiting factors influencing yield of field crops. Under any set of circumstances the response of yield to increased precipitation is sigmoidal so the greatest effect would occur in the steep part of the curve before other factors become limiting. The efficiency of weather modification would be determined by how close to optimum other factors influencing production are maintained. Therefore, weather modification should be conducted as part of a package designed to increase crop yields.

From the standpoint of an overall recommendations regarding national weather modification policy, the greatest immediate need is for evaluation of weather modification programs now underway or about to be launched. This should be done by an agency independent of the agency actually doing the work but should be linked to research facilities capable of recognizing problems and attacking these as they occur. It would seem that federal monies should be available for evaluation and research while state money is used for the practical applications. By a linking of practical application and basic research the maximum progress in extending and improving the technology should be attained.

References

Dennis, A. S., P. L. Smith, Jr., B. L. Davis, H. D. Orville, R. A. Schleusener, G. N. Johnson, J. H. Hirsh, D. E. Cain, and A. Koscielski. 1974. Cloud seeding to enhance summer rainfall in the Northern Plains. Final report under contract no. 14-06-D-6796, Division of Atmospheric Water Resources Management, Bureau of Reclamation with Institute of Water Resources, School of Mines and Technology, Rapid City.

Schock, M. R., J. A. Donnan, H. R. Swart, and J. L. Pellett. 1974. The South Dakota Weather Program: Administration, operations, and technology. DWM R-74-2 Division of Weather Modification, State Office Building No. 2, Pierre, S. D.

Schock, M. R., J. A. Donnan, H. R. Swart, and J. L. Pellette. 1975. The South Dakota Weather Program: 1974 Operation and results. SDDWM 75-1, Division of Weather Modification, Department of Natural Resources Development, Pierre, S. D.

Myers, Max, J. G. Ross, H. L. Hutcheson, W. Lytle, J. W. McCarty, S. T. Chu, O. E. Lanham, and R. K. Rudel. 1973. Effects of additional precipitation on agricultural production, the environment, the economy, and human society in South Dakota. Final report under contract 14-06-D-7158. Division of Atmospheric Water Resource Management, Bureau of Reclamation with the Agricultural Experiment Station, South Dakota State University, Brookings, S. D.

V-28. RICHARD DIRKS*, ATMOSPHERIC SCIENCE DEPARTMENT, UNIVERSITY OF WYOMING

One of the problems that I think still exists amongst atmospheric scientists and user disciplines is acceptance of the fact that we can modify the weather, that weather modification can work and we can predict the results. I think one area where this has been shown is the field of inadvertent weather modification and particularly on the local scale on the study of changes in climate and weather in cities. Many of the kind of modifications that we are talking about using agriculturally, I think have been shown to be present in urban areas. I might just review some of these.

Temperature changes are the most obvious, urban areas are typically warmer, minimum temperatures are often 4-10° warmer in urban areas. I am sure this is associated with a longer frost free period, longer growing season. Moisture variations have been shown to exist of the order of 10% from very nearby areas. Cloud cover is altered. A significant difference in type and coverage of clouds, precipitation, and in particular summer precipitation which is the biggest question mark in planned weather modification, is documented to be altered by urban areas. Amounts of 10-30% are apparently downwind increases. Solar radiation has been reduced by values of 5-10%. There have been evidences of other altered effects, severe weather, hail, tornadoes, thunder and so on.

The problem with the urban studies of course is in isolating the mechanisms. There are several major mechanisms involved. The altered land use, the altered aerosols and particularly the atmospheric related aerosols. Hygroscopic nuclei, ice nuclei and those pertinent to radiation. And it is a problem that remains to be solved as to which of these mechanisms is dominant in many cases. However, the effects are there and I think they certainly give support to weather modification that we can change these kinds of features that we are looking at and talking about.

V-29. WAYNE DECKER*, CHAIRMAN OF ATMOSPHERIC SCIENCE DEPARTMENT, UNIVERSITY OF MISSOURI

I would like to reiterate a couple things. Perhaps those of you who heard me over at NCAR yesterday will say there he goes again. But part of it is in relation to the going east again and this has to do with the fact that we have in the world recognizable areas that make the major contribution to the food supply of the world of 8 billion people that will be on the earth in the year 2000. If we are indeed going to do significant things about increasing productivity, be it better management, or better rainfall, I would suggest that this is the area we need to go to, the areas that are now producing the abundant foodstuff. These are the areas that will continue to bear the brunt of the responsibilities for producing food in the area. Fortunately for me, that happens to be a bit east of here as far as American is concerned. Water and farm management problems that are involved in those areas of the world will be the ones that will tell whether indeed we are going to make our responsibility for the agriculture of the country and of the world. It doesn't mean I am against producing food in the other areas of the world at all. I am just saying let us look at the big problem in our deliberation here today and when we go back to our own respective kind of places and look at things through our own eyes we'll try to apply them to that particular area.

Another thing I wanted to stress again and that is the concept of dependability. The question many are asking the modifiers today is, is the system dependable, as far as the addition of supplemental water to America's farms? Is the transfer from the experimental work to the operational programs there? Are we getting the people operating in our areas that know the things you guys are developing in your research programs and I am not pointing fingers at anyone. We just don't know out in the field. We are not aware of how complete this transfer mechanism is. You need to interact with us a bit in the next two days that we are here to make sure that we understand the extent of this transfer process. I have to say that I am concerned about the possibility of rainfall decreases during a seeding project. If it means that I have to support in the National Science Foundation or any other agency, I have to support work that goes back to the basic fundamentals of microphysics of clouds and the cumulus dynamics and all the things that deal with predicting what a cloud is going to do. I don't think this job is done and the process will not be complete until we have again gone back and studied some of the basic things dealing with cloud structure. The agricultural community ought to support that kind of research because it is something that we will have to have before we will get the application in the field, that we are here to talk about today. So I think this is the second major point that has been made by other people and I shouldn't have even said it.

My third point has to do with this people problem -- don't worry about the people problem. The people problem is in this room. If somehow we could come to a complete understanding of the potential for weather modification in agriculture we have the mechanism for selling this to the American farmer. The extension service works and sometimes it works too good. There are practices go out that we would like to pull back. We are not anxious to make mistakes in this area or any other. I would like to emphasize that there are mechanisms that are in the field today that will allow us to extend ideas very easily.

One other point that was brought up and I thought was quite good that needs to be thought about. That is that there is only available a finite amount of resource materials for us all to work with. Those of us in Universities are becoming more aware of this all the time. We are asked to squeeze our activities into a certain dollar value all the time. If there is to be increased resources to go into weather modification evaluation, weather modification research, research in agriculture that supports weather modification which is what you guys are telling us that we need to do, then something else has to give or else there has to be additional resources put into the program. And so, we are going to have to be helping a lot of people in important positions in American education and research administration assess some priorities because if we are going to ask them to do these things, then something else has to be curtailed. We will have to select the thing that has the best payoff. There are things that will have to change. We can't do things as we have always done them before in our educational research institutions. But we need to be sure that the priorities are the right priorities.

V-30 An Assessment of Weather Modification Research

by C. F. Chappell

Man has always opted for a safe environment in which to live, free from unexpected calamities and attendant suffering. Dreams of modifying his environment to make it more secure have frequently preceded the fulfillment of such hopes. However, capricious weather continues to plague mankind. It is natural then, that man dreams of exercising control over the weather, and complements these dreams with scientific investigations to determine their feasibility. These investigations have now spanned about 28 years. What has happened during these 28 years? Undoubtedly, different people would have various answers to this question.

It seems to me this period has been one of slow and erratic progress in weather modification research. This is due in large part to the extreme difficulty in measuring, understanding, and predicting atmospheric behavior, which if not first in complexity, must rank second only to the intricateness of human behavior. The period has been spiced by a few distinguished discoveries. A few experiments were well conceived, meticulously planned and perserveringly carried out. They represent milestones along our journey. However, poorly designed experiments have also been performed. Certain experiments, past and present, under close examination reduce to pathetic attempts to verify hypotheses, which were inadequately scrutinized at the start. Charlatans have appeared to pervert the field. Some remain today. A few well-meaning scientists, brilliant in peripheral scientific areas, but naïve about complex multi-scaled atmospheric behavior, have contributed to, and then lingered to hinder the overall research effort. In spite of growth pains accompanying the emergence of this new and inherently controversial science and technology, we can point to important progress.

Certain capabilities for perturbing weather systems have been recognized and developed. These include:

1. generating and invigorating convection
2. developing cirrus clouds
3. dissipating certain types of stratus clouds and fog
4. introducing aerosols into the atmosphere to affect the microphysics of cloud and precipitation processes or to produce thermal or chemical effects
5. manipulating the latent energy inherent within water phase changes

But after 28 years of plodding research, what do the advances add up to? What accomplishments do we embrace with some confidence? We consider these next.

The success in dissipating cold (droplets are supercooled or below freezing) fog to improve visibilities attained a level sufficient to warrant application of the technology to operational problems. More than a dozen airports are using this technology on an operational basis at the present time. Warm fog dispersal has proven more difficult to obtain, although direct heating from burners, mixing of drier air into the fog by helicopter downwash and seeding with some hygroscopic (salt, urea, etc.) substances have shown promise.

Notable success has been obtained in augmenting precipitation from cold orographic clouds (clouds that form when moist air is lifted over mountainous terrain). Results of several experiments suggest that seeding under certain cloud conditions can enhance winter precipitation by 10% to 30% over mountain ranges of the western U. S.

Successful precipitation augmentation has also been indicated by experiments in Israel and Southern California. The treatable cloud systems in these cases were convective clouds embedded in cyclonic storms which moved into mountainous terrain from the ocean. Seeded cloud systems produced 10% to 40% more precipitation compared to the non-seeded clouds.

Dynamic seeding, which increases the available buoyant energy to a developing cumulus cloud, has under certain conditions more than doubled the precipitation from isolated tropical cumulus clouds. It is still unclear what these increases mean in terms of areal rainfall, since the amount of convection is ultimately controlled by larger scale atmospheric processes, and invigoration of convection leads to increased stabilization of the near environment. This modification technique, as well as those techniques employed with the two previous cloud systems, require clouds that contain supercooled droplets.

Recently, studies have shown that summer rains have been increased from 10% to 30% in the vicinity of larger Midwestern cities. There is still some uncertainty regarding the exact cause of these observed increases, i.e. whether the city complex affects the dynamics, thermodynamics or microphysics of the cloud system.

There are several modification techniques in the experimental stage. Some progress has been made in using hygroscopic materials to increase precipitation from warm clouds. This technique accelerates the formation of rainfall by enhancing the coalescence growth of cloud droplets to precipitation size.

Modification techniques to mitigate severe weather effects have been slow evolving but some progress has been made. Controlled field experiments in lightning suppression are now in progress and preliminary results appear promising. Seeding lightning storms with nylon chaff has apparently reduced the number of cloud to ground strokes by 75% in one experimental program. Major programs in hail suppression carried out in Russia, Canada and more recently in the United States are adding to our knowledge. However, Russian claims of 70-90% reduction in hail damage have not been duplicated elsewhere. Recent numerical studies, combined with data from case studies of the National Hail Research Experiment, suggest the present seeding hypothesis may need re-examination, and may not be applicable to certain types of high plains hailstorms.

The modification of other severe convective storms, including tornadoes, is still very much in the research phase. Recent research in this country aimed at understanding and predicting the evolution of the severe storm environment in greater detail may point the way toward reasonable hypotheses for severe storm mitigation.

The mitigation of severe weather effects attending hurricanes is still in its infancy, even though serious modification research has been underway nearly 15 years. During this period the modification hypothesis has been altered, and the validity of the present one is seriously questioned in some quarters. Determination of the feasibility of modifying hurricanes appears to be many years away.

While progress has been made during the past, and important results have been reported in the last seven years, federal support of weather modification has been ebbing (For a full discussion of this paradox the reader is referred to "The Paradox of Planned Weather Modification" by S. A. Changnon, Jr., Bull. of Amer, Meteorlogical Society, Vol. 56, No. 1, Jan. 1975). The lack of support for weather modification research by the Department of Agriculture, the agency most apt to be affected significantly by its development, is an even greater paradox. This non-supportive role has been adopted in spite of substantial grass roots enthusiasm and recommendations by their own and university scientists. As we attempt to assess the present and potential role of weather modification in agricultural production, it may be wise to analyze the present attitude of the Department of Agriculture toward weather modification.

We believe the potential of weather modification in agriculture production for the foreseeable future lies mainly in modifications performed on the mesoscale of atmospheric motion (weather systems with characteristic dimensions of 20 to 500 km). Consequently, we believe present day weather modification can profit from a broader outlook and approach. Past reasearch efforts have been severely constrained to modifications on the smaller cloud scale. For too long, weather modification research has been considered within the exclusive domain of cloud physics, and other talents within the atmospheric sciences have not been fully employed. More creative and imaginative thinking is required in future research.

The immediate future appears to be an excellent time for a concerted move into Mesoscale weather modification. Firstly, results of some modification experiments on the more limited cloud scale suggest that even if successful, precipitation enhancement is not always economically feasible. Increases in rainfall from single clouds may not always produce enough additional water to make such operations practical. At the same time, it has been observed that when clouds organize into meso-systems, more substantial rainfalls are produced. Secondly, our capability for observing mesoscale weather systems has improved tremendously in the past few years and is becoming adequate for the problem. Thirdly, the technology for treating weather systems on the larger mesoscale is within our present capability to develop and employ. Finally, the mitigation of severe weather attending extratropical weather systems will likely depend on modification treatments introduced on the mesoscale to be effective. The short life-time of most severe convective storms decreases our capability to respond effectively after identification. A more promising approach is likely to be the inhibition or suppression of the storm by modifying the severe storm environment prior to generation of convection.

V-31 HENRY LANSFORD*, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Professor Decker said one thing that stimulated me to respond to very briefly. The people problem is a term that has been used to cover a variety of things. I think that Professor Decker was using it to refer to the problem of communicating to the people who are in a position to apply weather modification once it is established that it is usable. The Sierra Club was mentioned. I think there are a few other segments out there that constitute the people problem but I think one very important one is the state legislatures the national congress and the people who elect them.

I think there are a lot of interests involved. There certainly have been a number of conflicts. One in Colorado, the barley growers down in the San Luis Valley, were convinced the weather modification technology being used there benefitted them. There were a lot of other people convinced it was doing them harm and they went to their legislators and the upshot was that a committee was appointed in the Colorado legislature to consider new regulatory legislation to control weather modification in Colorado. I think primarily because of the efforts of Lew Grant who served as an advisor to the Interim Committee that worked on this problem, they had extremely good scientific input. They came up with the weather modification law of 1972, which I think is an extremely good one in that it provided a framework for allowing the potential of weather modification to be explored in the state. It also provides, through licensing and permits and procedures that involve public hearings, that the public interest is protected. I think it is a good law. Illinois recently passed one which had the same sort of input from Stan Changnon and some other people. My point here is that I think a collaboration between the sorts of people who are in this room, the experts both in the fields of meteorology and agriculture, and the input you can give to legislators and the public who elect them is extremely important.

Personally it appears to me very likely that national regulation will come along sooner or later unless adequate state legislation is established. My personal opinion is that national legislation might not be too desirable. There are so many different situations in different regions of the country that regulatory legislation that is patterned to try and take into consideration all the different sets of conditions, all the different applications, all the different requirements might leave something to be desired. Good laws like the ones Colorado, Illinois and several other states have now seem to me much more desirable than national legislation. However, I think federal legislation is likely to come along if, by default, the states don't consider this subject.

V-32 POSSIBLE SHORT-TERM EFFECTS OF WEATHER MODIFICATION ON RUNOFF FROM RANGELAND WATERSHEDS IN THE SOUTHWEST[1]

H. B. Osborn[2]

In the Southwest, most runoff occurs from snowmelt or thunderstorm rainfall. Most of the land surface of Arizona and New Mexico is arid or semiarid, and in these lands, summer thunderstorms are the major source of runoff. On rangelands in southeastern Arizona, for example, about 70 percent of the rainfall and almost all runoff results from intense thunderstorm rains.

Thunderstorm runoff results from short-duration, intense rain of limited areal extent. Runoff producing rainfall on a semiarid rangeland watershed such as the USDA 58-square-mile (150 km^2) Walnut Gulch Experimental Watershed in southeastern Arizona, results from thunderstorm cells that cover only a portion of the watershed (Figure 1). Efforts to increase runoff generally are concentrated on increasing the duration or intensity rather than increasing the areal extent (and thus decreasing the intensity).

A simple schematic cross section of thunderstorm rainfall with maximum depth of 0.1 in. (2.54 mm) is shown in Figure 2. For this analysis, as a simple, first approximation, the assumed result of cloud seeding, 0.3 in. (7.6 mm) is added to the center depth with no increase in areal extent.

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[1] Excerpt from a paper entitled, "Effect of Cloud Seeding on Runoff in Arizona and New Mexico", H. B. Osborn, and L. J. Lane, ASAE Annual Meeting, Davis, California, June, 1975.

[2] Research Hydraulic Engineer, United States Department of Agriculture, Agricultural Research Service, Western Region, Southwest Watershed Research Center, 442 East Seventh, Tucson, Arizona 85705.

Radar or mathematical models are used in most efforts to estimate the effects of convective cloud modification. In this analysis, storm center depth and runoff were determined for all storms on Walnut Gulch for 12 years of record (1960 - 1971). Storms were grouped in 0.1 in. (2.54 mm) increments, 0 to 0.10 in. (0 to 2.5 mm), 0.10 to 0.20 in. (2.5 to 5.1 mm), etc. Total runoff for all storms in each 0.1 in. (2.5 mm) increment and average runoff per incremental storm center depth were plotted against sotrm center depth (Figure 3). Storms were grouped by increments because the accuracy of estimating runoff from individual thunderstorms is highly uncertain. Twelve years were used so the less frequent exceptional storms were included.

The greatest volume of runoff resulted from storms of about 1.5 in. (3.8 mm). Above 1.5 in., the number of events decreased more rapidly than the increase in runoff per event. The two incremental curves cross between 2.6 and 3.0 in., indicating that an event in this range probably has a recurrence interval of about 12 years. In 12 years of record, there were two storms that produced runoff equal to the average annual runoff from Walnut Gulch. Obviously, such events can bias cloud seeding programs based on seasonal or annual runoff as well as randomized cloud seeding experiments.

Total runoff for 12 years of record on Walnut Gulch was about 3,500 acre-ft (4.32×10^6 m^3). Rainfall increments were combined to look at theoretical rainfall and runoff increases from an assumed increase of 0.3 inch in each event. The combined increments were 0 to 0.40 in. (0 to 10.2 mm), 0.40 to 0.80 in. (10.2 to 20.3 mm), and 0.80 to 1.20 in. (20.3 to 30.5 mm) (Table 1). Roughly 320 events of less than 0.4 in. (10.2 mm) center depth occurred in the 12 years of record. Total rainfall for these events was about 29,000 acre-ft (3.58×10^7 m^3). Assuming an increase of 0.3 in.(7.6 mm) center depth for each event, rainfall volume was increased to about 77,000 acre-ft (9.49×10^7 m^3) which is a large and appreciable increase in rainfall for range forage and small stock pond storage, for example. However, the predicted increase in runoff from Walnut Gulch is almost negligible because runoff production is normally small for such small events, and what does runoff is abstracted within the ephemeral sand channels before reaching the watershed outlet. The projected increase in runoff for 12 years was roughly 3 percent.

There were 160 storms in the next combined increment, 0.40 to 0.80 in.(10.2 to 20.3 mm) and about 47,000 acre-ft (5.8×10^7 m^3) of rainfall. The theoretical increase from seeding was about 50 percent to 72,000 acre-ft (8.88×10^7 m^3), which resulted in an estimated increase of 17 percent in total runoff. For the 75 storms between 0.80 and 1.20 in.(20.3 to 30.55 mm), seeding increased rainfall from 37,000 acre-ft (4.56×10^7 m^3) to 48,000 acre-ft (5.92×10^7 m^3), and runoff again by about 17 percent. For 32 storms between 1.20 and 1.60 in.(30.3 and 40.4 mm), seeding increased rainfall from 23,000 acre-ft (2.81×10^7 m^3) to 27,000 acre-ft (3.33×10^7 m^3), and runoff by about 9 percent. Adding 0.3 in. to the approximately 600 thunderstorm rains would increase the runoff by about 50 percent.

Increases in summer rainfall in the Southwest are normally most desired early in the thunderstorm season when the storms are most likely to be small. Successful seeding of these events would improve range conditions, but would have little effect on runoff from larger watersheds.

For downstream water users, the greatest value from cloud seeding would be to increase rainfall from the moderate-sized storms.

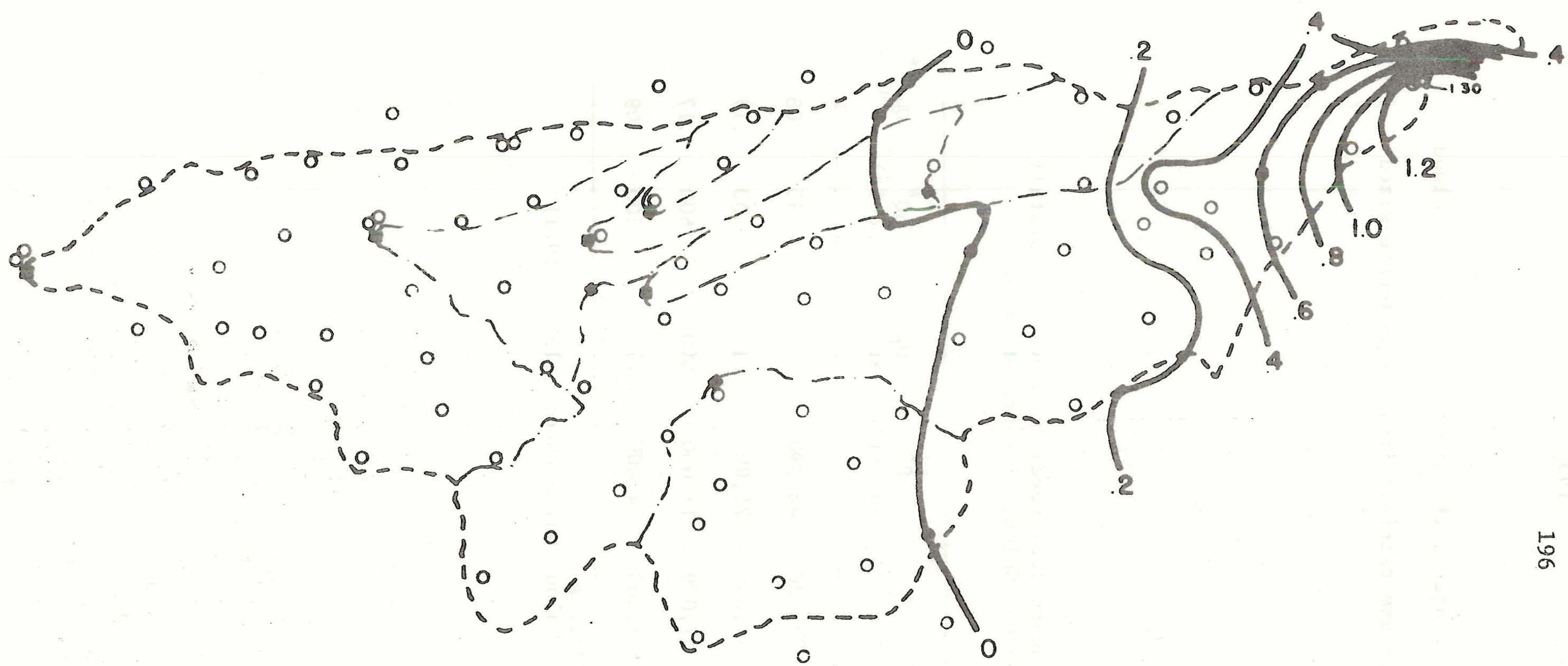
TABLE 1

Actual versus theoretical seeding values for rainfall and runoff on Walnut Gulch, 12 years of record.

P	Events	P (ac-ft)	ΔP^* (ac-ft)	Q_p (ac-ft)	ΔQ^* (ac-ft)	$\Delta Q/Q$ **
0 - .4	320	29,000	48,000	1	95	.03
.4 - .8	160	47,000	25,000	210	600	.17
.8 - 1.2	75	37,000	11,000	540	600	.17
1.2 - 1.6	32	23,000	4,000	770	300	.09

* Indicates seeded conditions

** Q = 3,500 ac-ft (total Walnut Gulch runoff, 1960 - 1971)



WALNUT GULCH WATERSHED

ISOHYETAL MAP

STORM OF JULY 21, 1964

Fig. 1

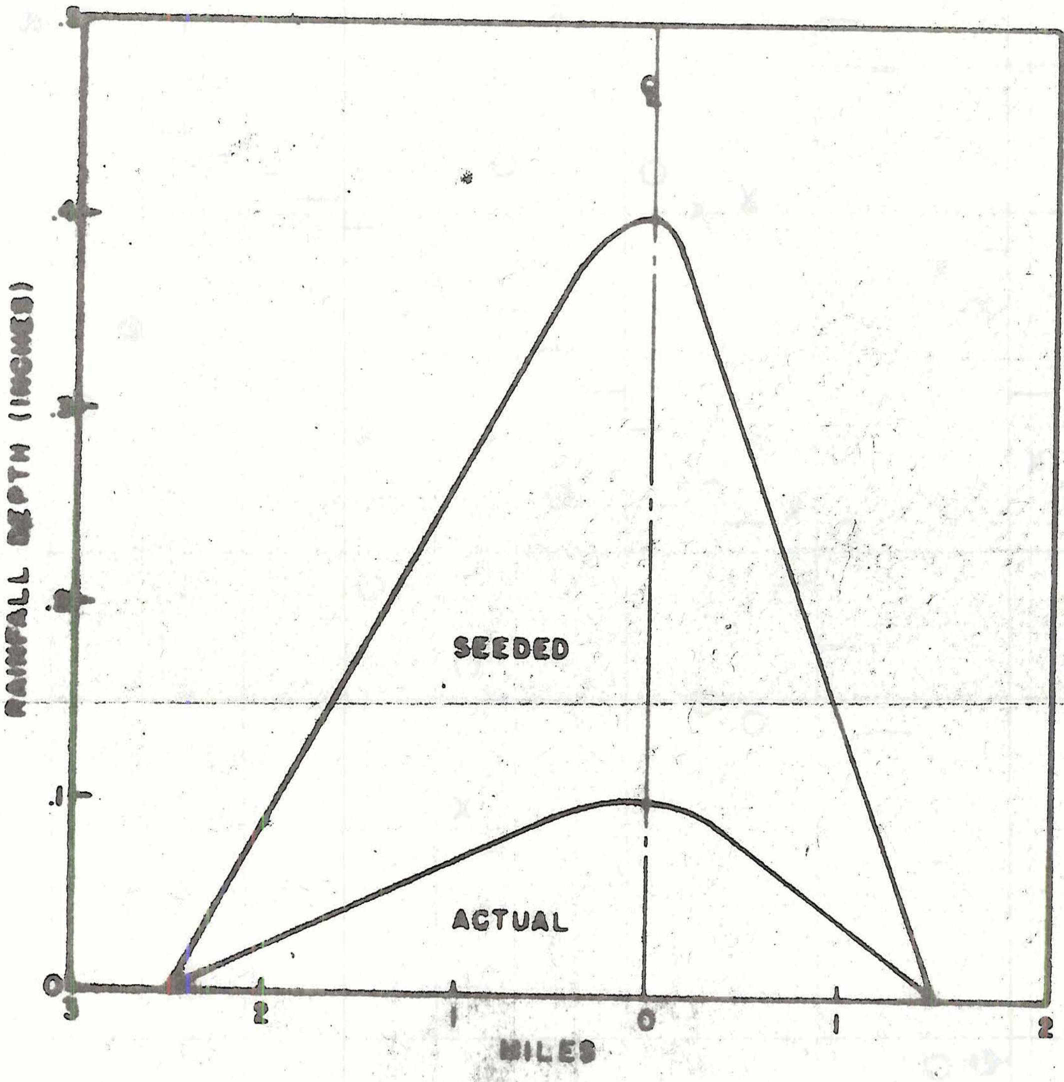


Fig. 2

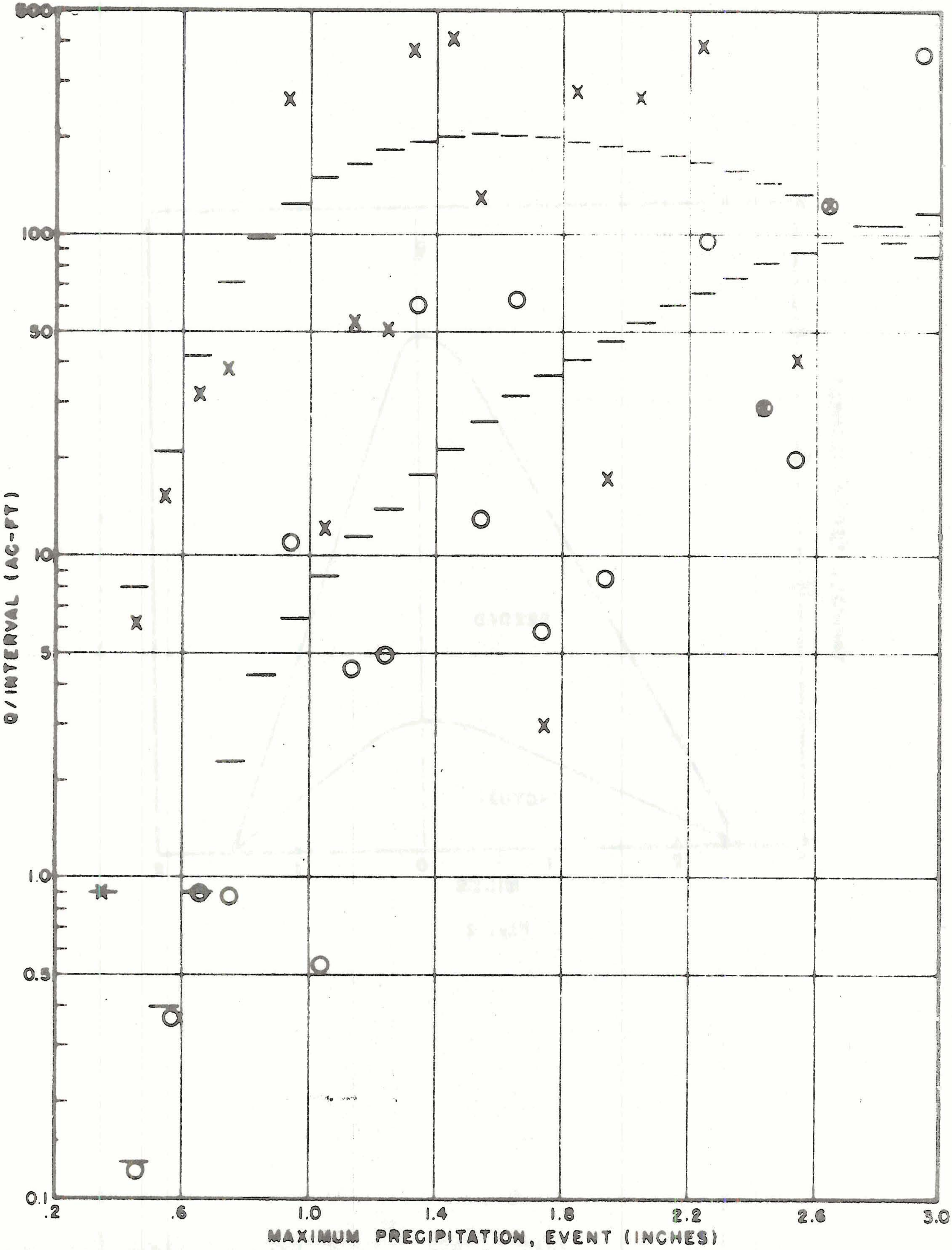

500
100
50
10
5
1.0
0.5
0.1
Q/INTERVAL (AC-FT)
.2
.6
1.0
1.4
1.8
2.2
2.6
3.0
MAXIMUM PRECIPITATION, EVENT (INCHES)

Fig. 3

V-33. WENDELL MORDY*, CENTER FOR THE FUTURE

There are organizational problems and there are problems of learning and it is cheap to seed clouds and it is expensive to evaluate seeding experiments. One of the most interesting freudian slips that has occurred was that the leader of the hail project at NCAR spoke about "hell" suppression and it passed almost unnoticed in the meeting. But in a sense no one has anything good to say about hail and nobody has anything bad to say about food. And in a sense we are talking about things that we can do without and cannot do without. But we are forgetting, I think, that the weather doesn't just affect the crops, it affects people as a group and I don't think that we are talking just about the Sierra Club.

I sat with Jules Charney who is chairman of the Department of Meteorology at MIT a few weeks ago and we were talking about policy formation with regard to weather modification. He said "Well, I don't think much of weather modification". I asked him why, and thought the response would be because he didn't believe the technology was ready yet, but no he said "I don't think people ought to fool around with the weather". Well, it was interesting because we had been talking just a few minutes before this about his own work, in which he had been working on the dynamics of deserts and he has found that the common explanation for the formation and development of deserts is inadequate and that the dominant factor in the enlargement and growth of deserts is a change in the albedo and the sinking of air. That deserts are not sources of heat as people might think, but sinks for heat, and the radiative cooling at night, low heat storage capacity in the daytime, causes the very dry high atmospheric air to sink and produce the very arid conditions that represent desert climate. He said if they really want to do something about the weather, they can plant trees along the Mediterrean Coast in Algeria and change the weather on a global scale. He is working with one of the most sophisticated simulation models in existence at this time. The feedback is enormous and the work is of considerable significance. Isaid Jules - your're in the weather modification business and I think he was gentleman enough to admit it when he made the remark and he was seriously considering the fact that there could be some beneficial effects from altering land use in some desert areas as a result of the implications of his work.

One of the things we can do most effectively in this kind of conference is to look at the means of effecting better communication and arriving at consensus. I thought Earl Droessler's remarks this morning were eloquent in that they addressed in a way that we all understood questions that have to be answered. I think weather modification research is essential. I am not talking about weather modification in the narrow sense. I am not just talking about cloud seeding. The meteorologists among us I think can all put forward suggestions where weather on small or large scale can be significantly altered. And altered and even fine tuned. I'll give you an example. On the Island of Oahu the rainfall gradients are very steep. There is a very sharp escarpment on the windward side and deeply eroded valleys running inland. The rainfall varies from 300-inches just near the eroded valleys. Now, it wouldn't take a lot of earth moving equipment to alter the rainfall regime here. But nobody in his right mind would go to the legislators and suggest doing this. People live there because they like to look at the waterfalls, they like to grow something. There are all kinds of reasons and people could not agree on how conditions should be changed.

In a general sense, that is the kind of problem we are going to have to deal with. In order to deal with it, we are going to have to know, if we know we are going to have to study it. People live in cities and people will decide. We aren't just talking to each other. I don't think that is enough. Since they live in cities, it has already been pointed out that the vast majority of people in this country, Changnon has repeatedly said this, live in man-altered climates. The big weather modification areas are Los Angeles, Mexico City, no one can deny that smog is weather. The fact is that we are going to have to deal with these subjects and the problem is how do we deal with it in a way where we can arrive at consensus. This means studying and the study will come and it should come in a way that optimizes the benefits for us all.

V-37 WEATHER MODIFICATION AND RANGELAND PRODUCTIVITY

by

M. J. Trlica
Range Science Department
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Roughly one-half of the land surface area is classified as rangelands primarily because they are too arid to be used for something more productive. In general these areas receive 30 inches or less of precipitation per year, and more commonly rangelands receive in the neighborhood of 15 inches or less of precipitation per year. I have done some calculations concerning the effects that one inch of additional precipitation would have on rangelands here in the arid west. I calculated something like 60 additional pounds of air-dried forage produced per acre on some of our native rangelands as a result of one additional inch of precipitation. This is really pretty insignificant when one considers that this additional forage might be utilized by some grazing herbivore and converted into approximately 5 pounds of additional animal protein. Therefore, we are not looking toward any great increases in productivity of rangeland with only a 10% or less increase in precipitation as a result of weather modification. However, if we can reduce the frequency or intensity of drought, this would make ranching a more economically stable enterprise. If we could only reduce the frequency of below average precipitation years, this would certainly make it more economically feasible for a grazing situation to be more productive. There are numerous data in the literature which indicate that

Literature Cited

Brown, L. F. and M. J. Trlica. 1976. A primary productivity model for blue grama. Submitted to J. Appl. Ecol.

Table 1. An assessment of the sensitivity of the primary productivity model predictions for blue grama (Boutelous gracilis) to variations in driving variables, coefficients and constants. The actual values of the model are compared to output produced when rather drastic perturbations are introduced by altering the indicated variables or constants (Brown and Trlica, 1976).

	Season totals (g $CH_2O \cdot m^{-2}$ ground area)								
	Pg[1]	Pn	AGR	Translo-cation	Root resp.	Shoot death	Root death	NPP	AGB max[2]
Original Predictions	1412	1188	224	1083	474	115	182	714	99
Changes made to the model									
Temperatures increased by 5 C	385	294	90	291	260	17	129	34	35
Temperatures reduced by 5 C	1660	1472	187	1279	365	200	197	1107	193
Temperatures increased by 10 C	105	65	40	77	395	3	69	-329	15[3]
Temperatures reduced by 10 C	13	12	1	99	145	18	97	-133	15[3]
Soil water potentials set at 0 bars	6466	5813	652	5028	1157	766	408	4656	759
Soil water potentials set at -50 bars or less	229	167	62	171	203	10	114	-36	20
Visible irradiance reduced by 10%	1162	970	192	889	436	93	166	534	79
Dry matter coefficient changed from 0.53 x AGB to 0.56 x AGB	1640	1380	260	1261	509	130	198	870	109
Reproductive translocation changed from 0.55 to 0.45	1680	1422	259	1271	488	160	192	934	145
Reproductive translocation changed from 0.55 to 0.65	1224	1023	199	953	464	84	176	561	80

[1] Abbreviations used are similar to those used in the text. [2] AGB max = peak standing crop of aboveground biomass. [3] 15 g $CH_2O \cdot m^{-2}$ ground area was the value used to initialize the model.

V-35. RAY BOOKER,* PRESIDENT, WEATHER SCIENCE, INCORPORATED.

In weather modification in 29 years what have we learned? How can we put the knowledge we've got to use? I hope as a result of this conference we will be able to do that. I've got to suggest that we've learned a great deal.

I sat in a meeting about 2-3 years ago and heard a cloud seeder tell a large group of people that if he seeded, he would eliminate drought from the Great Plains. There wouldn't be any hail and furthermore there wouldn't be any tornadoes. So they passed the hat and they developed a weather modification project right there on the spot. I am too young to remember. I think that is how weather modification was. How is it now? In contrast to that I will just use the state of South Dakota and although you have had a briefing on it from Jim we had another kind of weather modification project, an operation project. I am talking about now where most of the state (about 46 counties) have organized and they have a good means of funding the thing and representation from the grass-roots all the way up through the state level as well as input from scientists both within the state and from outside the state. They are using what I consider to be the state of the art. Arnett Dennis has written two reports so far where he has reviewed the ten years of research of the South Dakota School of Mines. He said, 1, 2, 3, 4, 5, these are the recommendations that we would make as scientists for operational weather modification projects. Here this project is using this. The five areas of weather modification people have to work are cloud selection, material selection, material delivery, observations, analysis, and reporting. I think the project is doing great things in this area. I don't mean to single it out as the only one but point it out as an example of how weather modification in an operational sense has come along way in 29 years. The research I won't even mention because you have already heard a lot of what has been learned today.

Well, if all this is true, why is there such a massive acute lethargy in the field of weather modification. Why can't we get it all together. Why is it that if there is such a tremendous potential for weather modification, I agree that there is, why is it that we are still just having scattered little projects here, one project over there. Why is it that we are only spending 15 or so million dollars on it a year in research if there is such a great potential here. Maybe there isn't as Dr. Chamberlain said this morning. But I suggest there is a great potential. What is the reason for it? I suggest that it is because we have not had on a national scale an organized effort to pull together those things we've learned. That is why I am so glad to hear about this conference. Because it is an attempt to get meteorologists and agricultural experts all in the same room. Maybe as a result of this conference we will pull some of what we have together. Now, I am suggesting that ultimately we have to have a national policy on weather modification. I am worried about how to develop this. And, I couldn't find any other way except to simply suggest legislation at the federal level. I have here a copy of what I have suggested. This is currently being considered in Washington. I think it will be introduced and I will solicit your support and the support of this conference on this sort of idea. In essence this is a followup to the Orville Committee. A suggestion is as follows: a commision should be composed of nine members to be appointed by the president and not more than two of whom are representatives of the following categories: federal government, the states, the colleges, private industry and so forth. The president shall appoint individuals who are known for their experience and competence in fields of weather modification research, operational weather modification, agriculture, agriculture economics, energy development, weather modification law, social factors, ecological factors and so on. In other words I am suggesting that a body made up of all the segments that are concerned with weather modification work in a concerted effort for at least a year to develop a national policy in weather modification. The commission would look into (1) the present state of development of weather modification technology, (2) the problems that still face the development of operationally useful techniques in weather modification technology, (3) the social and legal obstacles to the development of it, (4) how people who don't want the rain should be compensated by those who do. In essence I am suggesting that a commission be developed and appointed by the president authorized by congress to develop a document. In this document to summarize the state of our knowledge and put all this on a sheet of paper. Hopefully, if we chose this commission correctly we could get a body of evidence with the maximum possible degree of concurrence. Something that says to the maximum number of people - yes, that is probably about the best we can do in terms of a consensus of what we have learned in weather modification and its application. Then the next thing would say where should this nation be going, why is weather modification important if it is? I suggest it is most important for agriculture. Perhaps far more important for agriculture than for anything else. If it is the most important, and if so why. If it is this important, then the decisions that are made in Washington regarding where the funds go and how much funds could surely be guided by this. I would hope that the policy could be written with need to legislation regarding the funding for weather modification research and guidance as far as federal and state participation in operational weather modification. Hopefully, out of all of this we could answer what we have learned about this.

V-36. ROBERT ELLIOTT, PRESIDENT, NORTH AMERICAN WEATHER CONSULTANTS

This summarizes a few relevant points from the viewpoint of one who has been involved for over 25 years in the private sector of the weather modification field. My company started applying adaptations of Project Cirrus methods toward orographic snowpack enhancement for hydroelectric power generation in the early 1950's and has continued since then, adding innovative improvements in delivery systems, such as high elevation radio controlled generators, and in methods for monitoring operations along the way. We were also involved in a minor way in the early day seeding of summer cumulus; for example, in Iowa where we employed ground generators, an aerial seeding system, and a monitoring radar. We withdrew from this activity early, but have recently returned (to South Dakota) following the excellent field research carried out at the Institute of Atmospheric Sciences of South Dakota School of Mines and the implementation of the South Dakota state weather modification program.

The seeding of western mountain watersheds for increasing hydro-electric energy resources has benefitted agriculture by providing several million extra acre feet of irrigation water over the last 20 years, and this has been paid for by the utility companies.

With this perspective, it appears to me that weather modification has been timely, to use Dr. Wittwer's term, since the early work of Langmuir and Schaefer. I view the development of weather modification as being an evolutionary process, still on the accelerating portion of a growth curve, but in detail filled with many steps and a few setbacks. One such forward step was that taken by the Advisory Committee of Weather Control in the mid-1950's which lead to the assignment to the NSF of a weather modification research mission. Perhaps this meeting will lead to another forward step.

In the technological area, I have seen the slow but steady development of more effective means of monitoring the chain of physical processes leading from the emission of nucleant through its transport and dispersion, the conversion of supercooled water to ice particles on the nuclei, the growth of these particles and their final fallout onto the target area. These developments have improved the control of seeding as well as the evaluation of results. In earlier days such evaluation was focused on the end points of this chain, that is on generator locations and rainfall in the target area (and in control areas). If something went awry along the chain it was all but impossible to discover the error. Nowadays the picture is somewhat better.

In the area of cost effectiveness, again using Dr. Wittwer's term, the economic value of the seeding produced extra hydropower clearly exceeds all alternative possibilities. With respect to the extra irrigation water, the assessment is less clear. To judge from the Stanford Research Institute's Technology assessment for the proposed Bureau of Reclamation Colorado River Basin Pilot Project, it is of little value in a nation where restriction of farm production is (has been) subsidized. A Nader book on the Bureau of Reclamation also suggests that a zero value is appropriate for irrigation water produced by any future reclamation. On the other hand, there have appeared many resounding statements about the need to enhance agricultural production in all ways possible in order to feed a growing world population. I hope that the agriculturists gathered here can clarify these matters so we can set clear cut goals for our task.

Under the environmental (usually environmental/social) heading, I have seen a steady evolution in the consideration of the impact of seeding on diverse economies and environments within proposed target areas. It was during the 1950's that the public meeting got its start. A more acid test occurred when we were sued, along with our client, the Pacific Gas and Electric Company, for causing the Yuba City, California flood of December 1955. It was a long drawn out case and it was not until 1964 that the judge ruled that we had not caused, or contributed to the flood. The plaintiffs did not at first know that we had not seeded any part of the flood storm except the very beginning, and they had to change their approach to include a claimed enhancement of snowpack by seeding in the flood watershed during the month prior to the flood. However, the target watershed lay just north of the flood watershed, and all runoff was contained behind a dam. The plaintiffs were unable to prove that we had slopped over into the unprotected flood watershed.

The various weather modifiers, and others interested in cloud seeding have joined together in an organization called the Weather Modification Association. Among other things, this organization has taken a position favoring the establishment of a Weather Modification Commission whose membership would include representatives from a broad spectrum of weather modification users. The purpose of such a commission would be to formulate a National Weather Modification Policy. In my opinion, such an approach is sorely needed.

V-37

SOME ASPECTS OF THE APPLICATION OF PRECIPITATION AUGMENTATION TO AGRICULTURAL NEEDS

by E. Bruce Jones, Vice President
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Risk continues to be a major problem in agriculture. Floods, droughts, and insect infestations, as well as other natural hazards, have plagued agriculture throughout the ages. Modern science and technology have done much to quantify and to some extent alleviate these risks; however, some of these basic agricultural risks that can lead to reduced crop production are still with us.

Emerging technologies, such as weather modification, can further assist the agriculturist in alleviating some of his risks. One particularly intriguing aspect of intentional weather modification is the potential for precipitation augmentation.

Precipitation augmentation can have considerable impact on agriculture. However, to be realistic, the additional increments of water must be identified as to quantity and where they enter the hydrologic cycle. Only then can quantitative analyses be made as to the exact benefits.

Tangible identification of the additional increments of water may also become important in those States whose water law is based on the doctrine of prior appropriation. This doctrine, simply stated, is--the first to put the water to beneficial use is first in right. Thus in these areas, if additional water is added to the system by intentional weather modification, it will go into the priority system unless otherwise claimed.

Most western States also recognize the concept of developed waters or imported waters. Although individual State statutes may vary, these waters are generally allocated to those who import or develop new waters without regard to the priority system, provided the new water is adequately identified.

Recent studies by the author indicate that it would be potentially possible (albeit difficult) in several western States for an individual or group of water users to obtain some type of water right based on water

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1/ Prepared for Workshop on Weather Modification and Agriculture held at Colorado State University, July 15-18, 1975.

developed through the intentional application of weather modification. However, adequate proof of the amount of water developed must be provided to the court or appropriate judicial body. The State of Utah is a notable exception to this situation. Utah has passed specific legislation which in effect proposes to treat any additional water produced as part of the natural flow of the stream, and hence subject to prior appropriation.

Although filings for water developed through weather modification are potentially possible, they appear to be fraught with difficulties. Courts or appropriate judicial bodies must be convinced that specific amounts of water were actually produced. Such proof should be hydrologically oriented to show the additional "water in the stream" at some selected point. A right claiming developed water would probably be granted only after it is shown that there would be no damage to those who operate in the priority system. This means that losses would have to be shared, and any doubts as to quantity would be resolved in favor of the stream. Even if such a right were to be granted, it would no doubt create considerable community social stress during times of low flow. A basin-wide conservancy district or the State itself might better be able to file on such water.

The position of Utah should not be overlooked. It has aspects to recommend it, even though it may limit the activities of enterprising groups and individuals. The question of proof before a judicial body is foregone, and what may initially appear to be a windfall benefit to the junior appropriator can conceivably benefit the entire body of water users on that stream.

The use of intentional precipiation augmentation to provide additional water for agriculture is of apparent significant value, but the manner in which the additional water is injected into the system is also important. In order to maximize obtainable benefits from precipitation augmentation programs, policy should be carefully developed prior to actual implementation, whether the project be in the western portion of the United States or some other part of the world. Policy on this aspect of weather modification should take into account not only hydrologic conditions, but social, legal, and economic conditions as well. Consideration and implementation of these items in a systems approach should lead to further reduction of agricultural risk.

V-38. STANLEY CHANGNON*, HEAD, ILLINOIS STATE WATER SURVEY, UNIVERSITY OF ILLINOIS

The two questions we are concerned with here are: (1) can weather modification be done from a meteorological standpoint; (2) should it be done. These are the issues at hand that we have to grapple with. I think after doing a lot of work in both hail and rain considerations in Illinois, we came up with the fact that if we are looking at urban, industrial water supplies and all kinds of users, it was very clear, at least in Illinois and other comparable parts of the midwest, that agriculture is the main beneficiary. It is obvious by the attendance here. Another fact true of much of the midwest is that the benefits from rain exceed those of hail suppression. Another one of my platform issues is that there is a real need for establishing the economic value of weather. That is apparently what the agricultural input is in all this, if we are going to define the users and properly set the priorities out of this meeting or any other meeting. If the right users and the right priorities aren't set, you just can't sell it. I would like to mention as a part of my membership on this NC 94 committee that you have heard about, most of the members are here, Sylvan Wittwer got the committee to do last fall a statement on weather modification as it applies to the north central region. We have struggled over this. I guess we have got at least a semi-ffinished document written that does the things Ray Booker is talking about. There is a review of the status of the field, it identifies the key agricultural problems that weather modification might solve or alleviate and comes up with some recommendations including the need for first class experimentation in the region.

The final issue, which some of you may be aware of, is that we have had reasonable advances in weather modification, inadvertent and advertent in the last five to ten years, every august body there is has reviewed weather modification as go, great, it is needed, national need, and yet there has been a decline or leveling off in federal funding. As we all know, level funding is a decline, so possibly one of the solutions to this is what Ray talks about. The reasons as far as I perceive why weather modification has at least been a minature science in the federal scene is that it is still by more than one and a majority of the decision makers considered to be an uncertain science, emerging technology and it is probably fair game and so you don't put too many chips on something like that. The social economic benefits and disbenefits have not been clear. It has just been in the last two years that NSF and the Bureau of Reclamation has sponsored enough study that it is beginning to dimensionalize this. I would say there has been questionable management not only on the federal level but I think there has been a lot of scientific poor management. Solutions to this might be as far as I am concerned a major breakthrough like any big emerging technology that makes things go high order. It is obvious that if some foreign nation comes along with a major claim as they did with hail ten years ago, that that might put the old boom into weather modification. Overcoming it with a stronger constituency at all levels which I suspect is where we say we think we are or might be.

Finally, even with a bigger federal commitment, I think there are still a couple of key problems. The weather modifiers would say that we are still dealing with a very complex subject, that our knowledge is not adequate to the task and that that plus detection and evaluation times are going to mean that for the next five to twenty years, no matter what we do, developing technology for application to rain, and hail and hurricanes and everything else is a long way away. I don't think that should be denied. It has to be whatever this group or any group thinks that time is. There has to be a point, however, at which you go sell somebody, because that research is costly and it is going to require a long term commitment or as Charlie says a continuing optimism about the eventual prospects of weather modification.

V-39. LARRY DAVIS*, COLORADO INTERNATIONAL CORPORATION

We have experience in cloud situations that vary from tropical oceans to the artic during the summer and the middle of the desert. I think we all recognize that there has been a lot of bad news about commercial operations. But I would like to take Arnet Dennis's position and say let us forget about everything before 1965 or so, let us look at some of the good news that is coming forth in some of the most recent years.

The transfer of technology as Dr. Decker asks from research into operations I think is going very slowly. We are conducting certain operational programs that don't fly the technology that is available. I think there is considerable technology available. I also disagree with the contention that evaluation is expensive. To a certain extent it is. On the other hand if the operational programs are conducted in an appropriate manner, a type of monitoring is going on that is necessary to make the decision as to when where and how much to seed. The evaluation expense is considerably reduced. I think we have to take that into consideration as we look at the total cost of operational programs into the future.

In hail suppression, I think we are developing considerable evidence that we can suppress hail in certain types of clouds in certain areas. On the other hand, it is reasonably expensive to run a sophisticated radar with computerized processing and a couple of jet aircraft for delivery. In that case I think you have to look at the value of the crops that you are trying to protect. In some areas you are going to be quite profitable. Other areas are going to be very marginal. We also support the concept that you really need an active passive insurance program which we are developing in South Africa. It has been reasonably successful. When we get down to the nitty gritties I think we will find it is very difficult at this time to justify a hail suppression program just for hail suppression. It has to be combined with rain augmentation because the facilities, equipment and type of people you need for hail suppression is similar to what you need to do cumulus type rain augmentation. I think it has been said several times the economic return in terms of rain augmentation are considerably higher at least with the state of the art we have now than hail suppression. The economical size of operational units as we see it is an area that is about 60 miles radius centered on a radar operational center. This gives you the ability to operate with a 2-3 aircraft with a staff of 8-10 people.

In the area of rain augmentation I think that we have demonstrated the results that Joanne originally came up with that milking individual isolated clouds is a beautiful cloud physics experiment that has very little economic value except in a few limited cases where limited rain at a very critical time is economically worthwhile.

Therefore, in the area of rain augmentation I would like to push very hard for research applications in mesoscale dynamics in cumulus clouds. Worldwide convective rainfall at this time has the most economic return that I have been able to experience anyway. We find that techniques utilizing the promotion of cloud clusters can lead to considerable increased rainfall. When you speak about drought if you look at the frequency of precipitation class categories during the drought you tend to find what is missing is the 4-5 mesoscale storms that pass your area dropping 1-2 inches per storm. The frequency of the light rains really don't change that much. The mesoscale storms that produce 80-90% of your seasonal rain don't show up because there is a change in synoptic pattern. Through understanding mesoscale dynamics, promoting the clusters, we think there are marginal periods during these droughts that you can trigger a dynamic action that will lead to increased rainfall that could be of considerable economic value.

The question came up can you turn on and turn off weather modification. Obviously you can't. We do have crude but useful techniques for determining seedability. When you apply these to the climatology of various areas, we have done this in many areas in Africa, and then we got in and actually operated for a season or two, it is amazing how well the probabilities check out. Particularly for dynamic seedability of cumulus clouds. I would urge that we not say we are going to turn on or turn off but look at the probability of seedability and see how they line up with the probability of need at any certain period of time that a crop needs rainfall.

Finally, I want to say a couple of words about evaluation. We've been working at this problem for many years. In the operational parts of weather modification the proof is extremely difficult. However, I think that there are a lot of encouraging things coming along. We've been working with Paul Mielke on some new distributions, with Joanne Simpson. I think you will find in the next few years that we will come up with some reasonably good techniques that are like a lawyer trying to build a case on the basis of considerable circumstantial evidence. While each step may not be very conclusive the series of events is rather persuasive. We need to proceed in this direction.

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WEATHER MODIFICATION AND AGRICULTURE: A SOCIOLOGICAL VIEW

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WEATHER MODIFICATION AND AGRICULTURE: A SOCIOLOGICAL VIEW

Barbara C. Farhar

July 1975

One of the agriculturists at the Fort Collins meeting regarding weather modification and agriculture was heard to say: "There is no people problem!" This assertion was based on a profound faith in the Agricultural Extension Service in disseminating information to American farmers and in persuading them to adopt innovations.

Certainly the agriculturist was correct in pointing to the Extension Service as a nationwide organization with a history of effective transmission of research results to the grassroots level. But the nomination of the Extension Service as the panacea for all the sociological complexities of cloud seeding displays a lack of familiarity with the unique aspects of this technology.

There are two major reasons why the Extension Service, while it can be quite helpful in disseminating information about weather modification, cannot be considered a cure-all for "people problems" in weather modification. These two reasons are: (1) Weather modification is a collective innovation decision rather than an individual decision, and (2) Heterogeneity of weather needs and a complex of other factors go into the acceptance or rejection of any given weather modification project. Thus, knowledge alone does not a proponent make.

The Collective Innovation Decision

We are all aware that this century has produced incredible numbers of technological innovations -- innovations that have been implemented and have had profound consequences for our individual lives and our society, some of them totally unanticipated. Many of these innovations, once they were developed and introduced to the public, have been adopted by individuals. An individual can decide to plant hybrid seed corn or to use the birth control pill -- adoption of these innovations is a personal matter requiring no particular decision on the part of the community, once the technology is available.

Other new technologies, such as nuclear power plants and fluoridation, require decision making at the community level for adoption to occur. We must recognize weather modification as an innovation which was widely used by individuals -- by a farmer or small group of farmers, for example -- early in its history. As its application became more sophisticated, as it began to depend more on public funding, and as it was used over more extensive land areas, general awareness increased that the activity had implications for entire communities rather than only for the individual user. Weather modification thus became a collective innovation decision, or a public decision, requiring action on the part of a community or larger social aggregate in order for it to be adopted.

Because of the nature of the weather modification collective decision, it is important to study both systemic (or community-level) and individual variables if we are to understand the realities of the technology's social impact. Lest we view the adoption of weather modification as requiring an inordinate length of time to occur, let us examine research findings about the adoption rate of innovations.

Five characteristics of innovations have been found to contribute to their rate of adoption. These are:

(1) Relative advantage is the degree to which an innovation is perceived as better than the idea it supersedes. In the case of weather modification, the idea it supersedes is "Mother Nature," or for some, God, or passive acceptance of the vagaries of the weather. As one opponent put it: "Before we had only God and the Devil to blame for the weather, but now we have God, the Devil and the weather modifiers!" It matters little whether the innovation has a great deal of "objective" advantage. What matters is whether individuals perceive the innovation as being advantageous, including consideration of the risks involved. The greater the perceived relative advantage of an innovation, the more rapidly it will be adopted. A sense of high relative advantage is expressed by the farmer who says, "If I can possibly get some additional rainfall for my crop at 3¢ an acre with little or no risk, it is well worth a try. I'll support a program." A high benefit to cost ratio will affect perceptions of relative advantage.

(2) Compatibility is the degree to which an innovation is perceived as being consistent with existing values, past experiences and the needs of receivers. A compatible idea will be adopted more rapidly.

With regard to compatibility, weather modification is in an ambivalent position. Where its application is carried out in the regular free-enterprise fashion, it is consistent with the norms governing private enterprise. To the extent that these norms are acceptable, this mode of the technology's application would be acceptable. The idea of mastery over nature has a long tradition in Western civilization; yet the rise of the environmentalist social movement is at odds with that ancient desire. This aspect of the technology could thus be unacceptable to members of this social movement.

The concept of "weather needs" is highly sophisticated; most people would require an explanation of the idea. Yet needs for weather modification are evident in such social facts as crop damage from hail and drought, and destruction resulting from severe storms and floods. Where the expression of such needs arises spontaneously in the population, acceptance of the technology would proceed more rapidly.

(3) Complexity is the degree to which an innovation is perceived as difficult to understand and use. Some innovations are readily understood by most members of a social system; others are not and will be adopted more slowly. With regard to this variable, weather modification is destined to a long time lag in adoption, since it is a highly complex technological innovation. Understanding the physical mechanisms of meteorological conditions is no simple matter, yet such understanding is basic to a grasp of weather modification. Cloud seeding techniques require the use of sophisticated equipment and chemicals. Widespread use of the terminologies of meteorology and weather modification does not exist.

In addition to the complexities of the physical science aspects, the application of weather modification is uniquely bound up in legal, environmental, economic, social, agricultural and political ramifications difficult for the student to sort out, much less an individual adopter. Based on past experience in diffusion of innovations, the rate of adoption for weather modification will be slowed a great deal by its complexity.

(4) Trialability is the degree to which an innovation may be experimented with on a limited basis. An innovation that is trialable represents less risk to the individual who is considering it. New ideas

which can be tried out will be adopted more quickly. Here again, weather modification may be in for slow diffusion due to the difficulty of trial runs. At best, an experimental field project may be held in an area in order that locals can observe its results (in addition, of course, to its scientific purposes). But many locals will remain unaware of project effects and will not have the opportunity to observe the operations directly. These difficulties relate to the next characteristic.

(5) Observability is the degree to which the results of an innovation are visible to others. The easier it is for an individual to see the results of an innovation, the more likely he is to adopt it. The remarkable difficulty with weather modification is that it is virtually impossible to discern its effects "at the ground." The problem with observability in weather modification revolves around the natural variability of the weather, making it extremely difficult for the casual observer to distinguish accurately which weather effects are the result of cloud seeding and which are not. Weather modification's rate of adoption will be slowed by the difficulty in observing its effects.

Of these five characteristics affecting rate of adoption, three suggest a very slow adoption rate for weather modification (complexity, trialability, and observability), one is unclear (compatibility) and one may tend toward a faster adoption rate (relative advantage). We can also sense from this discussion that a rather slow and measured rate of adoption can be considered quite normal.

It should be noted that these characteristics related to the diffusion of innovations stem from research on individual adoption decisions. The diffusion of weather modification, as a collective decision, may not follow precisely the same patterns. But there are probably similarities in adoption patterns between individual and community levels -- with the patterns extrapolated from the individual to the community level.

Very long time lags have been observed in the adoption of most collective innovations; for example, adoption of kindergarten by virtually all of the public schools required 50 years. Collective decisions themselves require more time to occur than individual decisions; on the other hand, they tend to be more stable than individual decisions once they are made.

The Extension Service has been quite successful in involving farmers in the adoption of new and favorable technologies to increase food production. These innovations -- planting a new kind of seed, contour farming, and the like -- are applied as a result of an individual farmer making up his own mind to implement them. The applicability of Extension's approach to the application of weather modification would no doubt be of great assistance to the process of informing agriculturists about what the technolgoy can and cannot do, but it would be of limited assistance in the development of the requisite innovative decision mechanisms relative to program participation.

Factors Affecting Acceptance of Weather Modification

At the individual level, several attitudes and beliefs have been found to be related to acceptance of weather modification projects. Belief that it works, agreement with the idea of intervention in natural processes, and anticipation of economic benefit are associated with favorable program evaluation. In addition to majority favorability in survey results, we have found an approximate 11 to 20% opposed in South Dakota, Colorado and Illinois. This finding suggests that wherever a weather modification project might be proposed, opposition sentiment will be held by at least a tenth and possibly a fifth of the population in the area. Such sentiment might not be so keenly felt as to erupt into controversy; however, its existence is a social fact that is best not ignored by those who wish to apply programs.

Whether or not opposition sentiment will emerge into organized controversy and polarization at the community level seems to depend upon a number of factors regarding not so much individuals, but rather entire communities or areas.

In our research on social response to weather modification technology in the United States, we have indentified factors that appear to be related to the existence of organized opposition and acceptance of projects. We know, of course, that weather modification projects can be halted by organized opposition. We have observed that once an organized opposition has formed in a local area, it displays persistent, tenacious activity until it has successfully halted its local project. We know of no case where an organized opposition spontaneously died out with its goal unaccomplished.

We have observed and traced the development of an organized opposition network in the United States. The opposition is not as well-organized as the proponent network, but they have established and are continuing to establish linkages between previously more isolated local opposition groups. The sharing of resources that these linkages allow makes the opposition network more effective in dealing with local situations, although its power does not approach that of the proponent network.

We have found that negative weather events -- those causing economic loss -- are associated with opposition to cloud seeding. However, drought attributed to cloud seeding appears to be the one weather event more persistently associated with the formation of organized opposition than any other negative weather event.

We have found that responsive local governmental involvement in the civic aspects of the weather modification decision process is associated with acceptance of projects. "Civic aspects" pertain to participation, policy, suspension decisions, and the like, not to technical decisions.

We think that weather modification is inadequately regulated, with almost half the states (40%) having no statutes whatsoever. Those having statutes may not have comprehensive ones. There is some evidence that the existence of comprehensive legislation mitigates against the formation of organized opposition. Our interpretation of this is that organized opposition may be more likely to spring up in the absence of appropriate institutional controls of the technology's application.

Heterogeneity of weather needs in a local project area may lead to conflicts of interest. Some crops, for example, may need rain when others need sunny, dry weather. Given the potential for manipulating precipitation, who should decide whether there will be more or less rainfall? By what procedure should such decisions be made? If some people will experience disbenefit from a project, should they be reimbursed? By what process shall such decisions be made? These problems are not insoluble; they need not be ignored.

Innovation Packages

Innovation packages involving the simultaneous introduction of several activities have been utilized in the diffusion of new agricultural techniques. For example, in introducing hybrid seed corn to farmers, it was necessary to educate them in thick planting practices and proper application of fertilizers in order to make the seed corn most productive.

The concurrent adoption of the three innovative ideas was necessary for best results.

The analogy can be drawn to weather modification. Up until now, attention has been concentrated almost entirely upon the physical aspects of weather modification. Yet weather modification projects should be conceptualized as innovation packages. There are two other elements that must be introduced when cloud seeding is introduced. These are the concomitant physical adjustments to weather modification and the necessary decision mechanisms to permit social adjustments.

1. Physical adjustments. If rainfall can be enhanced in a given area, farmers will need to make adjustments in planting patterns in order to attain the most benefit from the increased rainfall. If hail suppression results in decreased rainfall, similar adjustments will have to be made. If snowpack enhancement produces 20% more moisture at the spring run-off, then physical adjustments in dams, placement of towns, use of agricultural lands, or levees might need to be implemented. These are examples of physical adjustments which might be required; their exact specification would depend on local conditions.

It is with regard to these physical adjustments that the Extension Service could be of great assistance to agriculture in maximizing the potential benefit from weather modification for food production. Actions that the farmer needed to take to enhance the benefit of additional rainfall, for example, involve an individual decision. This component of the innovation package is of crucial importance.

2. Decision mechanisms. Decision mechanisms need to be developed which take into consideration social, environmental and economic aspects of a proposed project. Feasibility studies should involve more than

climatology, agricultural needs, and hydrology. Problem areas need to be identified on a project-by-project basis and alternative solutions worked out for these before implementation. The participation of the attentive public in the decision process will increase community satisfaction with the final decision as well as provide valuable information to that process.

Avoidance of responsibility for social, environmental, and economic impacts of projects on the part of those running them will in the end be counter-productive for everyone. Acceptance of responsibility will aid in the anticipation of problematic situations and will make preventive action possible.

Because it knows local areas well, the Extension Service can no doubt contribute to the weather modification decision process, but it cannot itself make the necessary decisions. It can advise and counsel, it can work to develop a constituency, but, in the end, a decision by the polity will have to be made.

BIBLIOGRAPHY

Farhar, Barbara C. "The Public Decides About Weather Modification." Paper presented to Symposium on Establishing Goals for Weather-Climate Modification Activities, 141st Annual Meeting of the American Association for the Advancement of Science, New York City, January 26-31, 1975.

__________. "The Relationship of Socio-Demographic Characteristics and Attitudes Toward Weather Modification: The South Dakota Study, 1972." The Journal of Weather Modification, 5, 1, June 1973, 261-276.

__________. "Weather Modification and Public Opinion in South Dakota, Preliminary Findings 1974." The Journal of Weather Modification, 7, 1, April 1975, 145-153.

__________ and Sigmund Krane. "Weather Modification and Public Opinion: South Dakota, 1972." Interim Report. July 1973, 157 pp.

__________ and Julia Mewes. "Weather Modification and Public Opinion: South Dakota, 1973." Second Interim Report. March 1974, 190 pp.

Haas, J. Eugene and Sigmund Krane. "The Public View Toward Weather Modification in Illinois: A Social Assessment." Final Report to the Illinois State Water Survey. September 17, 1974, 90 pp.

__________ and Sigmund Krane. "The Social Implications of the National Hail Research Experiment." 1972 Final Report to the National Center for Atmospheric Research. February 1973, 133 pp.

__________ and Sigmund Krane. "The Social Implications of the National Hail Research Experiment." 1973 Final Report to the National Center for Atmospheric Research. December 1973, 130 pp.

__________ and Donald Pfost. "Social Implications of the National Hail Research Experiment." 1971 Final Report to the National Center for Atmospheric Research. February 8, 1972, 136 pp.

Rogers, Everett M. and F. Floyd Shoemaker. Communication of Innovations, 2nd Edition. New York: Free Press, 1971, 476 pp.

V-41 Climate Modification and Weather Modification

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Some thirty years after the dawn of the modern era of weather modification it remains a controversial subject. A few modification techniques have been demonstrated effective. Operational technologies exist. These can be immediately useful in enhancing agricultural production. Encouraging results are slowly emerging in other modification efforts. In the area of precipitation enhancement from summertime cumulus clouds, so potentially important to agriculture, there is sufficient evidence of effect that we can at least see hope for useful additional growing season precipitation input.

There are, however, disturbing effects of weather modification which have now been identified. Extra-area enhancement of precipitation is an effect deserving additional study. For a long while, a perceived problem of weather modification was that it would redistribute precipitation; robbing Peter to pay Paul. Studies are now accumulating which indicate that this is not the case. In fact it appears that precipitation is enhanced not only in the target area, but also in the downwind region. This effect leads to an in-balance in the hydrologic cycle which can be corrected by two methods:

1. Redistribution of precipitation occuring but the decrease being very slight and spread out over a wide area.

2. Water is pumped around the hydrologic cycle faster, with the increased precipitation being counteracted by increased evaporation, mainly in the moisture source regions.

In either case, because the effect is felt at great distance from the site of intended modification, the total effect is one of climate modification.

The effect on climate may be small, but would in all probability increase if weather modification were undertaken on a massive scale. Are widespread conventional seeding activities likely to produce significant climate change? Probably not, but we are still very ignorant about the mechanisms of the earth's climate. We cannot afford to just ignore possible climatic implications of such activities.

A number of proposals for advertent climatic change have also been made. Some of these have been noted in a recent review article called "Climate Stabilization: For Better or Worse?" by Kellogg and Schneider, published in the 27 December issue of "Science". They list such proposals as:

Eliminating Arctic Sea ice pack
Diverting rivers that flow into the Arctic Ocean
Damming the Bearing Strait
Damming the Gulf Stream
Transporting blocks of Antarctic ice to lower latitudes
Creating dust layers in the upper atmosphere

The list goes on. Imagine the international impacts of any one of these schemes.

Does this possibility of causing drastic alterations to the world climate suggest that we should immediately cease all modification activity? I think not. We should remember that the climate modification schemes proposed were proposed because they strike at susceptible "trigger points" for such efforts. The smaller scale weather modification activities are not so deliberately directed, and our inadvertent weather modification, such as from urban areas, is likely to be much more significant than these overt activities.

So what, if anything, should we do about activities that could bring about climatic change. It is clear that we have little ability to predict the consequences of advertent climate modification efforts. Thus, they should be banned until we have a capability to understand their important implications. It is not impossible that they could be predominantly unfavorable and irreversible. On the other hand, small scale weather modification effects are likely to be swamped by the effects of man's other activities (power generation, chemical waste disposal, automobile emissions). We should continue and increase monitoring of the atmosphere in remote locations to establish climatic trends. Finally, we should increase our efforts in climatic modeling in order that we may better understand the impact of all man's activities on climate.

V-42. PATRICK JORDAN*, DIRECTOR EXPERIMENT STATION, COLORADO STATE UNIVERSITY

Lew, I have to say, this is one of the most exciting groups it has been my pleasure to meet with in a long time. I suppose everyone is wondering what will become of these deliberations, and that is the real crux of it all.

In addition to enjoying yourselves, I guess I'm just tickled to death that it seems to be as productive as it is, because we're in trouble. We're in real trouble in agricultural research. Our funding, our recognition, the kind of appreciation we have from the tax-payers. It is nothing new. We've heard it before. But it really comes into very good focus particularly this week. I'm in favor of detente. Most of you are too, I suspect. I'm in favor of space research too, in fact my laboratory is funded by NASA today and it has been for a good part of fifteen years. So I'm in favor of it. But the Apollo-Soyuez launch which is circumnavigating the globe today and yesterday is costing more than all the agricultural research supported by the USDA for an entire year. That launch, important as it is, costs more than the aggregate of all the state experiment stations of all 50 states for an entire year. That launch costs more than half of the entire NSF budget for an entire year. So my question is either our priorities are a little bit twisted or we haven't done a very good job of selling the significance of what we are about. And so, the kinds of things you are doing today are crucial, crucial in that area.

I'm also tickled to see that you are facing the problems of policy, and the implications of policy, state, national and international. As we have seen over the past three or four years, the stroke of a couple of pens can have more impact on the agricultural economy than all the research that we've piled up during that same time period. We've got to have people in the agencies who know what the deal is. Here in Colorado we've been putting experiment station personnel for short periods of as little as two weeks to a three or four month period into key state agencies to try and develop that kind of rapport. To develop that kind of appreciation, that kind of interdependency that says you have knowledge, we've got to try and fit it together to meet the pragmatic problem. Of course, we haven't done any better at improving state funding for agricultural research in Colorado than we have nationally. When I say agricultural, I'm talking in the broadest sense, in terms of weather modification, in terms of weather research, in terms of land use and so on. Let me be specific. We arm wrestle over 20-, 30-, 50-, 100,000 dollar programs like they were the end of the earth for the state experiment station and a year ago the Governor with his blessing and so on opened a whole new program in energy research for about a million dollars a year and there wasn't even a plan on paper as to how they were going to go about it. So it is obvious that we haven't done something right. So, policy implications, involvement in the offices of people who are making policy, is extremely important and I'm glad that you did address yourselves to that question.

We've got to worry a little bit, I think, about the kind of communication we're engaged in now, this is exciting. We're talking about weather modification people talking to agricultural people back and forth. We're talking about importance of talking to the farmer about being willing to put up with weather modification efforts and so on. But we've also got to talk about the big mass of the American populous, the urban (and more than urbane) populous. Those are the folks who do call the shots when the real shots are called in the election process. I think we've got to talk to them about a lot of things, one of which is that again this year Russia's food production is going to come up with a roughly 10% shortfall. That's a pretty big shortfall when you talk about a country the size of Russia. China's having some problems, India too. We've got to worry about how we talk to them.

The national planning committee is an organ within the USDA-State Agricultural Station system the purpose of which is to try and prevent unnecessary duplication of research, to try to build on strengths and be able to tell legislators and executive branch agencies unequivacably that we know where we're going and why we're going there. These efforts aren't worth a darn unless the folks that really are involved in making that work mesh and mesh right. And so from my point of view, it is a big round of applause for you all and for the National Science Foundation in funding this particular workshop. These efforts are extremely important.

Dr Jordan's remarks were presented at the close of the conference

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