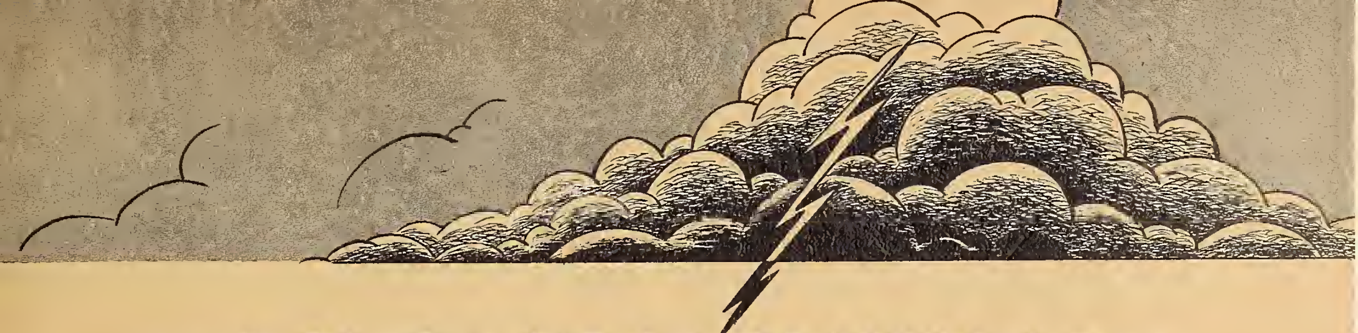

THE POSSIBILITIES OF MODIFYING LIGHTNING STORMS IN THE NORTHERN ROCKIES

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by

Vincent J. Schaefer
COLLABORATOR

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FOREWORD

Since November 13, 1946, when Dr. Vincent J. Schaefer first seeded a cloud with dry ice and caused snow to fall to the ground, practically everyone has been keenly interested in this remarkable possibility of "making rain." Forest protective agencies have been especially interested because of the possibility of causing clouds which pass over a forest fire to drop some of their moisture on the fire. At the December 1947 meeting of the Western Forestry and Conservation Association a resolution was passed urging Research to investigate this possibility.

In February 1948 Mr. H. T. Gisborne, Chief of our Division of Fire Research, called on Dr. Schaefer, Research Chemist of the General Electric Company, at his office in Schenectady, New York. Dr. Schaefer assured Gisborne of his belief that dry-icing could be used to produce moisture from certain types of clouds. However, when he learned of the large number of lightning fires which foresters have to fight, he said that "It may be that dry-icing will be equally or more beneficial to you by reducing or even stopping the formation of lightning in individual clouds."

The idea of stopping lightning fires at the source, in the clouds, is really revolutionary. Heretofore lightning has been considered the one unpreventable cause of forest fires. The possibility of merely reducing some of the peak loads of lightning fires (1488 in one 10-day period in 1940 on the national forests alone, in Region One) obviously offers a clear opportunity of aiding fire control. Even under conditions more "normal" than those of 1940, if only a few threatening clouds could be neutralized on lightning storm days, the fire control force would be better able to do its job, undoubtedly with less men and at lower cost. All agencies, federal, state, and private, would benefit, because a lightning storm, once started, may travel 50 to 100 miles across forests of many ownerships.

We were therefore extremely pleased when Dr. Schaefer volunteered to come to our Priest River Branch Station and personally examine the possibilities. For three weeks he watched and photographed lightning storms as they developed over the three "breeding spots" in that part of the Kaniksu National Forest. What was wanted was the development of at least two separate lightning storms. First, both would be photographed from incipiency to violent activity. Then, at the next occurrence, one would be seeded with dry ice while the other was used as a check. Lapse-time movies of both would again be taken so that the evidence of success or failure could be examined by anyone interested.

Dr. Schaefer wanted to test his theory, he did not want to select conditions to "prove his point." The Forest Service was ready with an oxygen and radio-equipped plane to make these tests as soon as two separate clouds developed to the stage in which it was certain that both would produce lightning.

Such clouds did develop over each of the three breeding spots, but every time they developed they also spread out and joined instead of remaining separate as they normally do. A plane could have been sent up and dry ice applied but there would have been no clear photographic evidence. Consequently no tests were made.

For his time in making these field studies and in preparing his report neither Dr. Schaefer nor the General Electric Company made any charge. Dr. Schaefer served us officially as a Collaborator without salary. He is continuing to give us his advice. It is a pleasure to express publicly the appreciation of the Forest Service.

Chas. L. Tebbe

CHAS. L. TEBBE
Director

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THE POSSIBILITY OF MODIFYING LIGHTNING STORMS IN THE NORTHERN ROCKIES

By

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BASIC THEORY

The supercooling of water is a very common and universal phenomenon. Despite the common belief that water always freezes at 32° F (0° C) it can be easily shown that clouds of small water droplets normally cool to temperatures of 0° F (-17.5° C) without the formation of any ice crystals whatever. If it were not for this supercooling phenomenon we would not have the serious hazard to airplane flight through cold clouds which sometimes coat propellers and wing surfaces with heavy loads of ice. Neither would we experience intense lightning storms if clouds did not supercool.

It is only when a large cloud supercools to a high degree that the stored up energy becomes great enough to produce the effects observed in a thunderstorm. It is now believed that the intensity of the thunderstorm is directly related to the amount of supercooling and the liquid water content of the cloud, together with its vertical development and turbulence.

Supercooling can only persist in a cloud when there is a low concentration of ice crystals in it. This concentration may be as much as ten crystals per cubic centimeter without greatly affecting the stability of the supercooled cloud. However, as the vapor pressure of water is greater than that of ice at all temperatures below 0° C a supercooled cloud is potentially in a very unstable condition. Thus whenever the concentration of ice crystals becomes approximately equivalent to the number of cloud droplets (100-500 per cubic centimeter) the droplets rapidly evaporate as the crystals grow.

It has been demonstrated in the laboratory (1) and the natural atmosphere (2) that clouds of supercooled water droplets may be completely changed to ice crystals by the introduction of small quantities of dry ice into the area containing the supercooled clouds.

Tremendous numbers of ice crystals are produced by the proper use of dry ice (solid carbon dioxide). Quantitative studies have shown that about 10^{16} ice crystals may be produced per gram of dry ice. Thus one pound of dry ice, which generally costs less than five cents, will produce 5 times 10^{18} ice crystals under optimum conditions in the free atmosphere. If there were enough moisture available to permit each particle to form an ice crystal 1/32 inch in diameter approximately 150,000,000 tons of snow would be produced per pound of dry ice.

Under practical conditions there is neither enough moisture available in the atmosphere nor is it possible to distribute the dry ice efficiently enough to produce <u>and</u> <u>sustain</u> the potential quantities mentioned above.

It is obvious, however, that if only 0.1% efficiency is obtained the use of dry ice as a cloud modification medium presents an intriguing possibility to produce large effects in cloud systems having areas of supercooling.

It is this fact, which can be proven experimentally, in either the laboratory or the natural atmosphere, which has indicated the feasibility of modifying cumulus clouds after they have grown big enough to become potential lightning generators if their growth continues. A simple calculation shows that if we assume that the supercooled portion of a potential lightning cloud system has a vertical development of 10,500 feet, and a base of four square miles, about 30 pounds of dry ice should, if efficiently distributed, produce a concentration of ice crystals within the eight cubic miles of cloud of about 500 ice crystals per cubic centimeter. This assumes that 10% of the dry ice is effective in producing crystals at the rate observed in past experiments.

Because of these favorable relationships, and as the result of successful field operations, it has been the belief of the writer and his co-workers for some time that it might be feasible to modify potential lightning clouds and perhaps cause their dissipation under favorable circumstances.

As in any new science it is necessary to do a considerable amount of exploratory work, experimentation, and basic research, using adequate controls in all experiments, before the possibilities and the limitations can be recognized.

ACTION TAKEN

Interest of Forest Service in Lightning Storms

On February 4, 1948, Mr. H. T. Gisborne of the Northern Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, who is in charge of Fire Research for Region One, stopped in the laboratory at Schenectady to learn more about our cloud modification studies. In our discussion he pointed out that lightning causes about 75% of the forest fires in his region and that in 1940 some 3,113 fires were attributed to lightning strikes, with about 1,500 fires occurring in one 10-day period.

As the cumulus cloud system which leads to the development of the thunderstorm is one of the types in which our research group of Project CIRRUS is particularly interested, I told Mr. Gisborne that if I could make the necessary arrangements I would spend a few weeks during the summer at the Priest River Laboratory to conduct a study of such clouds. I emphasized the importance of establishing in a very definite way the genesis, growth, maturity, and dissipation of normal cloud systems and was much interested when he informed me that there were three locations within 20 miles of the Experiment Station which seemed to serve as cloud breeding spots, due to local topographical features.

With this prospect, and in addition with what seemed to be ideal laboratory facilities, I made preliminary plans to go to Priest River in the middle of July.

The Forest Service, through Mr. Gisborne's initiative, agreed to furnish living quarters, office space, laboratory facilities, a car for reaching the summit of Looking Glass Lookout (elevation 5,500 feet) where the main observations would be made, and whatever instruments might be needed in addition to those brought from Schenectady.

In return for this cooperation I agreed to make as detailed a study of the cloud systems in the vicinity of the Experimental Forest as possible in the time available, and when the study was completed to render a brief report of the observations made, together with whatever recommendations for future activities might seem to be worth while.

Activities At the Experiment Station

Plans progressed satisfactorily and I arrived at the Priest River Station the evening of July 17. After unpacking and becoming established I looked over the facilities and was most favorably impressed with everything. The next morning I decided it might be well to install the atmospheric electricity instrument so that we would start gathering information as soon as possible. It was fortunate that this was accomplished because the first lightning flash occurred just as the ground wire was being connected. The ensuing storm was the most active of those experienced during my short stay. A total of over 200 strokes was recorded in a three-hour period, most of which probably were strikes occurring within a radius of 15 miles. It was not possible to make any photographic records, primarily because this storm was not of a purely local nature. As it approached it was already in an advanced stage consisting of six or more active centers, within the sensitive range of the instrument.

During the 20 days spent at the Station we had an almost discouraging sparsity of lightning storms. As so often happens in research, and it seems to be particularly the case in weather studies, the start of a program is the signal for the cessation of the activities to be studied!

Although 19 lightning storms occurred in June and 5 in July, all previous to my arrival, only three occurred in the time I was at the Station. The record shows that the present year is the wettest in 35 years of observations exceeding the wettest year previously recorded by more than 5" at the present time and exceeding the median value of 28 inches by more than 15 inches. The net result of this present weather situation is a very low fire danger and apparently a decrease in potential lightning storms due to the lack of heated land and water areas. Probably this is only part of the general weather situation which has affected the present program.

Despite the relative lack of lightning storms five days were utilized for cumulus cloud studies when orographic convective clouds occurred within the observation region. On three of these days the clouds contained supercooled regions having vertical thicknesses from 1,000 to 12,600 feet. No lightning occurred on these five days although precipitation fell on August 2 from those clouds reaching a height of 25,200 feet above sea level.

Presence of Cloud Breeding Regions in Area

The observations which were made confirm the statements made to me by Mr Gisborne that in the local region are three specific areas where large clouds form which may subsequently become thunderstorms. These regions as seen by me are as follows: the conclusions of course being based on seven days of observations.

Most active - Area above Looking Glass, or summits 5-9 miles north, extending east of Priest Lake.

Second most active - Area above ridge between North and South Baldy about 20 miles WNW from Looking Glass. This is by far the most interesting region for observation and study both for alidade and photographic purposes. Of exceptional value is the fact that one can use the ground shadows of the clouds to determine their closest distance and the long ridge and prevailing winds cause them to move toward the NE so that their development can be watched for several hours. Of significance also and further supporting the importance of Baldy Ridge as a cloud generator, is the fact that the first local clouds seen in the morning usually appear there.

While the clouds start forming above the ridge they slowly move eastward so that by the time they have reached full development the center often is above the Pelke Divide and Meadows, ten to twelve miles from the observation spot on Looking Glass.

The third region where clouds commonly start forming is in a region east of the Newport Flats. This does not seem to be of a desirable nature for study purposes with camera or alidade because of the sun's position. It is a very useful development to watch however because of the optical effects which may be observed as the cloud sometimes reaches up and hides the sun.

Another active region partly visible from Looking Glass is an area N or NE of Pend Oreille Lake. Clouds generally form there and move up the Purcell Trench toward the Kootenai Valley. These are too far away to be of interest if the observations are to be made from Looking Glass.

In view of these features I seriously doubt if a better situation could be found for cloud modification studies of large cumulus clouds which in normal season regularly produce lightning, than that available in the vicinity surrounding the Priest River Experimental Forest.

Measurement of Atmospheric Electricity

One of the important aspects of lightning storms is the atmospheric electricity which accompanies them. Lightning discharges from cloud to cloud, cloud to ground, and ground to cloud are important features not only from the standpoint of fire research and control but also are of basic importance if we are to obtain a better understanding of the fundamental structure of these destructive and dangerous storms.

Excellent studies (3) have been made in recent years using radar, aircraft, and ground networks to obtain a better understanding of these storms but much remains to be done if we are to eventually understand all of the significant features.

A simple method for recording certain of the major electrical characteristics of lightning, rain, and snow storms has been developed (4) and used by the writer for about five years.

The essential units of this device are as follows:

1 needle point collector
1 insulator rig
1 12-foot pipe for holding collector
1 length of shielded, single conductor cable
1 lightning arrester
1 recording photoelectric microammeter 5 μA full scale
1 ground wire

A unit was brought from the Research Laboratory and installed by Gisborne and the writer at the 150-foot meteorological tower at the Experiment Station. The needle point is at the top of a 12-foot long pipe which is strapped to the railing on top of the tower. The shielded cable connecting the insulated point to the recording microammeter passes down alongside of one leg of the tower and from the base goes to a small instrument shelter nearby. The lightning arrester protects the instrument and a ground wire goes to its negative terminal.

The recorder chart may be operated at fast or slow speed. During snow or rainstorms a slow speed is sufficient to record the significant data. Under such conditions a speed of 2 inches per hour is used. During lightning storms it was found that a speed of 2 inches per minute was adequate.

An excellent record was obtained during a brief but intense storm that swept by west of the Station shortly after 9:00 a.m., August 4, 1948.

This was an interesting local storm. It was observed to form above Hoodoo Mountain just south of Priest River village shortly before 0900 and then suddenly started moving in a northwesterly direction. It stayed within the Priest River valley hugging the rim of mountains along its west side and sweeping over a path about 5 miles wide. The first lightning strike was recorded at 0900, about 11 miles south of the Station, and the 77th about 47 minutes later at a distance 11 miles to the northward. Some of these were multiple strikes either occurring along the same path or as much as a mile apart.

The strikes plotted by the observer on Looking Glass Lookout were on the nearside of the storm and totaled 22. He did not include several seen to hit Priest Lake. Gisborne and Barrows observing from the meteorological tower noted 51 cloud to earth strikes but they agree that they did not see all that occurred nor have time to note all that were seen. At the time of writing I am informed that four fires were started by this storm. Subsequently seven more were found.

The record of the instrument thus indicates that it should be useful in supplying an automatic record of the total number of strikes occurring within a radius of about 12 miles of the Station.

The induced current which causes the phone bell to ring as a storm passes over and lightning strikes, is of course another indication of the intensity of the storm. A correlation of the strikes and bell rings may easily be made, to see if this may also be used to evaluate certain features of the storms.

The character of the atmospheric electricity on days of thunderstorm activity may be a very useful criterion of the effects of seeding operations. After several seeding operations are accomplished, with adequate controls to demonstrate differences, it may be desirable to see what can be done to modify a lightning storm which has already started to produce strikes. Convective type thunderstorms over flat land generally pass through a definite sequence of developments and it may be impossible to cause much if any effect on such a storm system. On the other hand a storm generated by orographic lifting often produces a series of storms one following close behind the other. Such a situation might be modified quite successfully and if accomplished the record of the rise and fall of the atmospheric earth to sky potential would be invaluable.

To prepare for such a possibility, records should be obtained of natural storms so that all of their features may be readily recognized. The recording microammeter is therefore being left at the Priest River Station for continued operation. Instrument charts and notes concerning storms registered should be sent to me for examination.

Certain Features of Cumulus Clouds Bearing On the Operational Procedure for Seeding Them

In recommending procedures for carrying out experiments in modification of cumulus clouds it should be recognized at the outset that any suggestions made in this report are of a tentative nature and subject to revision. I am convinced, however, that a method will eventually be developed for completely modifying that type of cumulus clouds which produce lightning, hail, severe "cloud bursts", destructive winds, and similar undesirable phenomena.

Whether this method is practical, economic, and feasible are questions which can be answered only by those research people who are willing to conduct careful experiments, and do so with enthusiasm and imagination.

It has long been recognized that towering cumulus clouds up to the cumulus congestus stage have high altitude, high turbulence, high liquid water content, and a high degree of supercooling. Two clouds measured on August 2 could easily have been modified with dry ice since they contained between 9,300 and 12,600 feet in vertical thickness of supercooled cloud. No trace of lightning occurred in these or in any others seen during that afternoon, although light rain showers occurred under a few of them. A cloud measured on August 1, 1948, on the other hand, reached a height of 26,000 feet mean sea level before any trace of snow development occurred. There was approximately 14,400 feet of vertical thickness above the freezing level before snow was evident. Forty minutes after this glaciation was observed rain was seen below the cloud base and 99 minutes after glaciation the first lightning occurred. Heavy rain fell from this cloud which moved slowly at a rate of less than five miles per hour. Only three cloud to earth lightning strikes were seen although there may have been double or triple that number. This storm was, however, a mild one in terms of strikes and movement when compared to the one on August 4 which moved 20 miles in 45 minutes and produced 77 lightning strikes. This latter storm delivered much less rain on the ground which may be an important factor in evaluating intensity.

Flight Operation Requirements for Seeding Cumulus Clouds

There are certain basic requirements for conducting seeding operations on towering cumulus clouds. These are briefly as follows:

1. At least one aircraft capable of climbing to 20,000 feet within a reasonable time period (30-50 minutes).

2. Oxygen equipment suitable for some movement by photographer and observer.

3. Insulated bags for transporting and handling dry ice.

4. Thermometer for measuring air temperatures from plane at various altitudes.

5. Camera equipment suitable for obtaining good photographs. (At least 3-1/4 x 4-1/4 Film Pack Super XX or equivalent and an A (red) filter.)

6. Hammers, and 2" x 4" x 4' for cracking and fragmenting dry ice. A crushing machine should be obtained eventually.

7. At least 150 pounds of dry ice should be available for the initial experiment. (This is least expensive item of operation since its cost usually is less than five cents per pound.)

8. Sieve with 14 mesh screen of box type 2' x 3' for sieving dry ice.

9. Suitable radio for communication with summit of Looking Glass, and possibly with the steel tower.

10. Notebooks with time entries minute by minute prepared in advance and capable of being strapped on leg if possible. Pencil tied with cord to notebook.

Preparation of Dry Ice for Use in Seeding

Commercial dry ice normally is shipped as 10" cubes. Unless it is kept in a well insulated box or bag it evaporates rather fast. It will lose more than half of its original volume in a day unless well insulated. It should not be broken into pellets until shortly before being used, although if necessary fragments 1/2" in diameter may be kept overnight without much loss, in a case having four inches of glass wool or its equivalent in heat insulation.

Dry ice is rather difficult to reduce to small fragments without suffering a considerable loss by powdering. It is "horny" in texture and does not fracture as easily or as cleanly as water ice.

The simplest method for breaking up a few hundred pounds of this material is to have it cut by the dealer into 1" or 2" slabs which may then be cracked up with a hammer or small sledge and then reduced to smaller fragments by pounding with pieces of wood such as a 2" x 4". Fragments should not be larger than 1/2" in diameter because such a fragment will fall nearly two miles before it completely evaporates.

The powder resulting from the cracking process should be separated from the larger pieces if the air is humid, otherwise condensation tends to cement the powder and the larger fragments into large solid chunks. This separation is most easily done with a 14-mesh screen sieve. The powder may be used if it is carried in separate containers and care is exercised to break up the caked mass before it is dumped into the cloud.

The best method for temporary storage and transportation to the seeding region is to employ the canvas bags used by the Forest Service to drop hot meals to firefighting crews. About 30 pounds should be put into each bag. This will permit easy handling and will be a good quantity to put into a cumulus tower for the early experiments. The shipping containers in which the dry ice is obtained from the manufacturer also may be used.

Just before dumping it the bag should be shaken or kneaded to loosen any caking that may have formed in storage.

If the plane is well ventilated there will be no danger of getting an overdose of carbon dioxide. Leather or cotton gloves are necessary to protect hands during work with dry ice, and safety glasses should be used when reducing the chunks to fragments.

It is suggested that at least 150 pounds of ice be carried on the first few flights.

Selection of Clouds for Modification

It is essential to obtain complete records and information during the early flights. The following procedure is suggested:

1. After checking all equipment and facilities the plane should be on alert for operation during lightning season.

2. If possible, and time permits, a practice run should be made to test equipment, cameras, dry ice source, radios, observers, use of notebooks, dry ice handling, break-up and dispensing, oxygen units, temperature measurements, and other items which can be sources of slow down and trouble. This should be done preferably when there are some clouds available, but if possible, without waiting for what might be considered to be ideal conditions. It should be considered primarily as a "dry run" to shake out troubles and find out where the general plan may be improved. As mentioned elsewhere every attention should be given to getting as much good information as possible on <u>every</u> flight.

3. Assuming that all "gear" is on hand, the dry ice is prepared and stowed near the open door, observers are alerted, personnel are at hand and engines are turning over - the plane takes off at a time early enough in the day to reach the clouds as they are forming high towers but in their relatively early stage. Under "good" conditions this should occur between 11:00 a.m. and 2:00 p.m. The plane heads for a high altitude circling above the Sandpoint airport. As it swings into good position for cloud photographs in the direction of the ridge between North and South Baldy several pictures are taken with careful notes being made of the time of each photograph. As the plane reaches 8,000 feet it would be advantageous to fly over Looking Glass to alert the observers there. This may be done as part of the climbing flight operation. Reaching the 20,000-foot level the plane should fly at right angles to a line between Looking Glass Lookout and Baldy Ridge and at a distance of about 20 miles (which would be just about over the lookout). During this run several pictures in rapid succession should be taken of both control and experimental clouds. At this time the heading of the plane should be noted by the co-pilot as well as altitude, time, temperature, and air speed. The photographer should, if possible, include a small portion of the wing tip or the tail in the picture as he photographs the clouds. This may be useful subsequently in analyzing the photography.

4. After these preliminary photographs are taken the pilot immediately heads the plane for the cumulus tower selected for the first experiment and approaches within a few hundred feet of it. If he tops it he should drop to within a hundred feet of its top and the contents of one bag (25-30 pounds) of dry ice scattered into the cloud. If the cloud is a simple one and only has one big "tower" he should fly away from it immediately and get into a favorable position to permit the photographer to get some new pictures. This position should be in the same region if possible where the earlier photos were taken. Again two or three pictures should be snapped in quick succession <u>of the same view</u>. This will produce a pair of pictures which may be viewed stereoscopically. If changes are noted plane should remain in general region for at least a half hour unless observer on Looking Glass indicates that he will secure the desired photographs. Even if this is the case photos should be taken at this position from the plane about every three minutes for at least 15 minutes. In each case pairs should be taken 10-15 seconds apart.

If after 15 minutes new cumulus heads appear in the same cloud system another seeding pass should be made and the preceding photographic sequences repeated.

If instead of a single cumulus tower several are noted, a batch of 25-30 pounds should be scattered in each.

If the cloud selected cannot be topped, a short flight into it should be made dispensing the dry ice while inside the cloud. Care should be exercised, if the cloud is entered, that everyone is securely fastened to the plane.

In every instance when cumulus type clouds are seeded an effort should be made to see that the selected cloud region has a "hard" surface and is not "frayed" This hardness is a good indication of active growth within. This activity can be utilized to help in the efficient spread of the dry ice fragments.

After photographic work is completed (this time should be long enough to establish whether the cloud was dissipated or unaffected), the plane observers should attempt to examine the cloud at close range to become familiar with its general properties. If large amounts of snow are produced (as will be the case if the cloud is stabilized) some unusual sun pillars, streaks and halos may be seen by placing the observers between the modified cloud and the sun so that the sun's disc is visible as a blurred, fuzzy image. The reflection of the sun can often be seen by looking toward the sun but at a region at the same angular depression below the horizon as the sun is above it.

After completing its mission the plane is returned to port. The first job after landing should be a critique and a general discussion of impressions, opinions, and observations of the results of the experiment. Notes should be made by each observer or his comments should be recorded for subsequent analysis. All notes should be completed, signed, and dated immediately.

Unless this sort of control is exercised most of the experiments will be useless. In a similar manner data should be gathered from the observers on Looking Glass and all pertinent weather and other instrument data accumulated as soon as possible. If this type of procedure is followed the results cannot fail to be of great importance and the project will be well worth while.

Observation Procedures On Looking Glass Summit During Cloud Modification Tests

The exceptionally favorable position of the summit of Looking Glass summit with respect to the Baldy Ridge area permits it to be used as an observation site thus adding greatly to the experiment planning and operation. In fact the use of the summit is better than equivalent to having another plane in the air since the base stays fixed at all times.

In operations of Project CIRRUS we generally make use of two aircraft, one of them assigned to the dry ice seeding operation and close-up investigation, the other, the control plane, carrying meteorologists, photographers, and the flight controller. This latter individual controls the seeding plane by radio. As this plane stays from five to twenty miles away from the seeded area the controller has an exceptionally fine opportunity to size up the general situation and direct the plane to go into the regions which look to be the most vulnerable for modification.

Under normal conditions Looking Glass summit could serve as the control site provided trouble-free radio telephone communication can be depended on between the summit and the seeding aircraft, and that a person capable of "sizing up" clouds can serve as controller. I do not suggest that this method be used in the early tests but would like to point out the unusual opportunity that is available at the Experiment Station in this respect.

Observational activities on Looking Glass should be planned with the foregoing items in mind so that its advantages may be utilized as the experiments proceed. Also this summit might be an ideal radar site eventually, particularly at the ridge auxiliary lookout, 1/3 mile east of the manned lookout. (This is the site of the old "Experiment Station Lookout".)

The following items should be on hand at the summit during the initial tests:

1. One observer in addition to the lookout man and his wife. 2. A plane table and alidade 3. One radio telephone tuned to the Experiment Station and the plane radio. 4. One pair of binoculars. 5. One still camera and a good supply of film. 6. One notebook and pencils. 7. One watch with sweep second hand. 8. Chart showing height as a function of distance from the observation station.

All planning should be done before the flight assuming that there will be no communication between the summit and the plane. Poor visibility from the mountain due to intervening clouds or rain showers is a possibility although this will hardly ever occur under ideal or even normal conditions.

Before plane take-off the observer on the mountain should be at his station and should report to the plane radio the situation as he sees it paying particular attention to the cumulus build-ups over North and South Baldy and the ridge between. With plane table and alidade he should be measuring the elevation of cloud base and top and reporting them to the plane.

As soon as it is apparent that activity is well under way (this generally becomes noticeable when the height of the cumulus is about double the width of its base) the plane's pilot should be notified and should take off immediately.

On the mountain, plane table-alidade sights should be made every few minutes of the active towers, and careful notes made of the location of the shadow of the cloud with respect to the terrain. (Radio communication with other lookouts should be of value here.)

Photographs should be made every five minutes after plane take-off and should be increased in number to one every two minutes as the seeding occurs. This should be continued for at least 30 minutes afterward or as long as it is feasible to recognize the cloud region under study.

The number of hard surfaced towers observed should be noted, not only in the treated cloud but in several others in the same general area.

It should be emphasized that at least one other cloud region should be photographed in addition to the one to be modified. This is essential for demonstrating changes in "normal" behavior produced by the seeding.

A running log of observations minute by minute should be made with the assistance of the lookout observer or his wife.

Time should be synchronized with that of the observers on the plane. This should be done by radio just before and just after the flight.

Among the observations made from the summit should be the following factors of both the treated cloud and the control cloud or clouds:

1. Base and height of cloud.

2. Location of cloud shadow.

3. Time of final fraying of hard "towers" or "boils".

4. Time first precipitation is noted.

5. Course of precipitation area.

6. First lightning time and location.

7. Nature of lightning whether indistinct flashes, strokes confined to the clouds, or strikes from cloud to ground, and the number of each.

8. Activity of other clouds to N, E, S, and W.

9. Time of appearance of glaciation or other visible evidence of snow.

10. Final appearance of both the treated and control clouds.

It is obvious that it is going to require an experienced observer on the summit to do a good job, in fact, it may require more than one person. These questions can be answered only by actually going through the procedures suggested to see what is required.

While at Priest River I spent several days with Mr. Gisborne going through these various procedures so that he is quite familiar with them.

In addition to the observations suggested in this report others may be added as experience is acquired.

Both the plane operation and the summit observations should be planned so that if one observer fails to get needed information the other one may be able to save the situation.

I cannot be too emphatic in pointing out that we are dealing with a new science and are pioneering in many phases of the job. Enthusiasm and imagination both are of much importance in the early stages of all such developments. So far as possible those in charge of the work should be relieved of the feeling that satisfactory results must be forthcoming or the project ends. Basic research never succeeds under such conditions.

No matter what results are obtained the research, if well conducted, will be well worth while.

RECOMMENDATIONS

In view of the situation previously described and recognizing that a larger number of observations may alter our present understanding of the problem I should like to make the following recommendations for the serious consideration of those in the Forest Service interested in lightning in the Northern Rocky Mountain region:

1. That a definite, simple, but complete set of observations of lightning storms be initiated and carried out at the Priest River Forest Experiment Station for a period of at least five years.

2. That a serious effort be made to secure as observer on Looking Glass a person having a fair amount of training in meteorology preferably a married student who is majoring in meteorology. It might even be possible to arrange with either the University of Washington, California or some other school having an active department in meteorology to give credits for such observation work The observer in addition to fire watching would be expected to make detailed observations of local thunderstorm genesis and all other weather phenomena of interest or peculiar to the region. Since there is not much possibility of fire on lightning days until the storm is fully developed, I think the opportunity for securing valuable information on lightning would be unique. It would be worth while to consider extra compensation for this work though I doubt if this will be necessary if the plan is worked up properly.

3. The following are observations that may be obtainable on most lightning storms of an orographic nature in the local area:

a. Location and starting time of cumulus activity.

b. Height of cloud base and its relation to the dewpoint and relative humidity.

c. Time from start of cumulus activity to final fraying of top.

d. Appearance time of first rain flush after fraying.

e. Appearance time and location of lightning strikes with respect to rain area.

f. Height of highest tower with hard surface.

g. Number of hard surface towers which develop.

h. Movement of precipitation area with respect to topography and area.

i. Seriousness of resulting storm.

j. Reason for lack of lightning formation at times from cumulus congestus clouds. In all observations careful records should be obtained of time, temperature, winds and optical phenomena that may be associated with the cloud development.

k. Throughout the observation season records of atmospheric electricity should be obtained at the 150' steel tower. In good observation sequences supplemental data such as radio-sonde reports and other complementary data also should be gathered from the CAA and other sources. Whenever possible good photographic records should be obtained.

4. Cloud experimentation.

a. The region centered about the Priest River Forest Experiment Station seems to be ideal for cloud modification studies. For this reason and because of the seriousness of the lightning problem in this region I suggest that plans be laid for a series of seeding flights under the direct supervision of H. T. Gisborne to investigate the possibilities of such activities in modifying the clouds to minimize or perhaps even prevent serious lightning.

b. Initial flights should not be attempted without careful planning and the selection of ideal situations. By this latter reference I mean a cloud situation consisting of two or more similar but separate towering cumulus systems approaching thunderstorm stature. The seeding operation would be carried out in one system, while the other would be used as a control. The results observed in initial operations should be viewed with caution. However the results obtained with proper seeding should produce effects unlike those generally observed in natural storm developments. Good photographic records should be obtained both from the seeding plane and from Looking Glass, as well as eye witness accounts gathered immediately after the test. I have instructed Gisborne concerning the types of records desired.

c. If possible at least one practice test should be scheduled to make sure that the various phases of communication, observation instrumentation, seeding techniques, high altitude operation, dry ice preparation, photography, etc., are under control. The general details are covered earlier in this report.

d. These practice flights should not be considered final tests although if by chance the proper clouds happen to occur as the test gets under way care should be exercised that all data obtainable are gathered.

e. It should be recognized at the start of flight activities that the whole science of cloud physics is in a very early stage of development. Recommendations made at this time might be - in fact probably will be - revised, as experimentation proceeds. One basic fact should be remembered - <u>any cloud which is supercooled</u> can be <u>completely changed to a snow area</u> by using the proper technique in "seeding" it with dry ice. If a large number of crystals are produced (a number equivalent to the number of cloud droplets) the cloud will tend to be stabilized and will persist for a much longer time than a water droplet cloud. If a critical concentration of ice crystals is introduced (a number probably equivalent to one-fifth to one twenty-fifth of the number of cloud droplets) then the cloud probably will be precipitated in the form of snow or rain, dependent on the temperature of the air in and below the supercooled cloud.

f. Initial experiments in stabilizing towering cumulus having a vertical thickness between fifteen and twenty thousand feet should employ from 25 to 100 pounds of dry ice. So far as calculations show and experiments indicate such treatment should produce a stabilization of all the supercooled area in the cloud, shifting the cumulus form to false cirrus and alto-stratus structures In mountain regions such as in the vicinity of Priest River it may be necessary to carry out the modification operation in successive stages as new clouds form in the breeding or generating areas.

g. Eventually we hope it will be possible to locate ground installations producing sublimation nuclei which will be carried up into the clouds to produce effects such as now are obtainable with dry ice. Much experimental work must be completed however before I would recommend the field use of this method on lightning producing clouds. The principle behind this process is the production of sub-microscopic (invisible) smoke consisting of a crystal having the ability to serve as a nucleus for a snow crystal. The most successful substance to date is silver iodide (5). Silver iodide smoke will persist in the air for a considerable period and unlike the dry ice effect does not require that its environment be saturated with respect to ice with water vapor. When it is introduced into a water droplet cloud supercooled to a temperature between -5°C and -10°C each sub-microscopic crystal serves as the nucleus for a snow crystal. Active work is under way in our laboratory in this field at the present time and it would be well if the Experiment Station is prepared to make tests along such lines if desirable.

h. The development and practical use of seeding projectiles also is under active consideration and eventually might be usable at mountain-top installations.

NOTE: Items "g" and "h" are mentioned to emphasize the importance of obtaining basic information as suggested in items 1, 2, and 3. With a clear picture of the possible cloud generating regions, the development of natural storms and the other important features of these weather phenomena, the Forest Service would be in a favorable position to test, and evaluate cloud seeding methods and other techniques which are rapidly developing. I am sure the incidental information which will be gathered during the period would alone more than repay for any costs that may be involved over and above the normal operational costs of operating the lookout and any other items such as instrumentation.

i. If it is decided to make plans along the lines suggested it would be a wise policy to get the advice and cooperation of enthusiastic persons in various fields who might assist in laying out a comprehensive program of research. This need not - in fact - should not, be too elaborate but it must include the basic information which is now believed to be required. The plan should be flexible enough that changes can be made, new observations added and useless ones discarded as the study proceeds. Dr. Phil Church of the University of Washington, Dr. Edward Evans of the Pittsfield, Massachusetts Works of the General Electric Company are the type of men I have in mind. I would be very glad to help, also.

j. If it is at all possible to obtain the use of radar observations to augment the data this would be very desirable. Such an installation is a very expensive one, however, and requires the services of expert operators and maintenance men. It would be ideal if, as urged by Gisborne, the U.S. Weather Bureau would install and operate such a unit on Mount Spokane. It would be in easy range of the Priest River region. Special photographic records could be secured on especially favorable days to supplement the general observational records. If on a few of such days seeding operations also could be conducted valuable information would result. I would not recommend, however, that any part of the suggested program be deferred until radar is installed. Good photographic records of isolated storms supplemented by atmospheric electrical data and visual observations with alidade and plane table would provide excellent information.

In conclusion I should like again to emphasize my considered opinion that there are few if any locations in the United States which possess the unique characteristics of terrain, weather, personnel, facilities and economic values already present at the Priest River Forest and Range Experiment Station of the U.S. Forest Service. If properly designed and carried forward with the scientific attitude which thus far has marked the other research at this field laboratory, a lightning study program as outlined would constitute a distinct contribution to fire research. This should be of real value to those of us interested in weather research and the new science of experimental meteorology.

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