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POTENTIAL EFFECTS OF CLOUD SEEDING IN MICHIGAN

By

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ABSTRACT

POTENTIAL EFFECTS OF CLOUD SEEDING IN MICHIGAN

By

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A precipitation climatology was developed for the April-September growing season in Michigan. This climatology is used to assess cloud seeding potential throughout the state.

Gamma distribution parameters were determined weekly throughout the growing season for 101 stations. Maps showing rainfall over the state at the 50% probability level were drawn for each week of the season.

Cloud seeding models of Huff and Changnon were used to modify historical rainfall. Gamma distribution parameters were calculated for modified rainfall and maps constructed for the 50% level precipitation. Maps were also drawn of increased rainfall amounts.

These maps are used to determine optimal time periods and locations within the state for cloud seeding.

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INTRODUCTION

In this paper the assumption will be that cloud modification does work and that the enhancement (or decrease) of precipitation will follow definite models. The purpose of this paper is not to prove whether seeding clouds, in the many methods available, can alter the natural precipitation of a cloud system or systems. Thus, the study will consider the potential for augmenting precipitation in Michigan.

Weather modification, or at least the attempt at it, has been around since the time of primitive man. Dancing, rainmaking rituals and praying to various rain gods were all ways in which man attempted to produce rain.

Prior to World War II, scientists experimented with various materials and discovered that some could change the processes that nature provided to produce rain. The prospect of additional rain when and where it was needed was so exciting that expectations exceeded the capability to apply the concept. After thirty years of investigations, proof--in the scientific sense--that seeding clouds can actually produce an increase in rain is very limited" (Bark, 1978).

Weather modification, however, is still a very new and complex field, and we haven't dealt with it long enough to understand the many complex processes involved in the formation of rain, let alone the possible modification of it. This idea is summed up in an introductory statement from the International Conference on Cloud Physics: "An old wisdom from the Far East says: you cannot tell how the flower looks if you know only the seed. You have to know first how the bud looks" (Neiburger, 1967). In other words, since only a few steps involved in the formation of rain are known we cannot predict with much certainty what will happen when clouds are seeded at any given instance.

The objective here is to develop a "cloud seeding potential" climatology for Michigan. The procedure will be to investigate both spatial and temporal patterns of precipitation across Michigan. Weekly precipitation patterns of both naturally occuring warm season precipitation and of modeled precipitation will be determined.

It is hoped that this information will serve as a guide in determining the regions of greatest potential benefit for cloud modification and lead to a more efficient allocation of time and money to be used in cloud seeding projects.

FORMATION OF PRECIPITATION

Clouds and Adiabatic Processes

The processes that form precipitation depend on the prior existence of clouds in the atmosphere. This is one of the primary reasons why scientists cannot produce rain in a sky devoid of clouds.

Clouds are a collection of tiny water droplets which fall at about the same speed as the air rises, therefore the cloud appears to be stationary drifting with the wind. These water droplets can form when the air is saturated with water vapor, i.e., reaches near 100% relative humidity.

The atmosphere follows adiabatic laws. Air can become saturated by being forced to rise to a higher elevation. This lifting can take place as air is forced to rise along hills or mountains, or by being overtaken by a colder, more dense air mass and forced to rise over it. Air will also rise if heated by the sun. This method occurs principally in the warm seasons when the sun exerts its strongest influence.

As the air rises, cooling and subsequent saturation will result. Moisture then can condense on small particles of dust and smoke commonly known as condensation nuclei that are always present in the atmosphere. This will form tiny cloud drops, about .01 mm. in diameter.

Raindrop Formation

Precipitation can be formed by two methods usually referred to as the "warm rain" and the "cold rain" processes. The term "warm rain" stems from the assumption that rain in tropical oceans was formed from clouds that were warmer than $0^{\circ}C$ ($32^{\circ}F$). The "cold rain" process, on the other hand, occurs in clouds below $0^{\circ}C$ ($32^{\circ}F$). The term "warm rain" is not accurate since this process also occurs in cold clouds as well.

Warm Rain Process

In the warm rain process, precipitable size drops form when smaller droplets collide and coalesce with each other. Coalescence will take place when droplets of varying sizes falling at different velocities in the atmosphere come into contact with one another. Once cloud drops grow sufficiently large, they can continue to expand by colliding with smaller drops, or they may split apart. With this process repeating itself, small droplets forming into large drops, rain can reach the ground in 10-20 minutes from a developing rain cloud.

Cold Rain Process

In tropical oceanic regions, giant condensation nuclei are present. These nuclei allow large drops to form permitting coalescence to produce rain before the cloud dissipates. Over continental regions this is not the case. The cloud condensation nuclei present are more numerous, but much smaller. The average size clouds formed in these locations would dissipate long before producing rain via giant nuclei processes. Thus, another process has to be present to account for precipitation over continental regions.

The cold rain process occurs where temperatures are colder than $0^{o}C$ ($32^{o}F$) within the cloud. Spontaneous formation of ice crystals occur in regions of supercooled $<0^{o}C$ ($32^{o}F$) water droplets. These ice crystals act as condensation nuclei, just as the warm rain process involved condensation nuclei.

At temperatures below freezing, more water vapor is required for saturation over the liquid surface than over the ice surface. Thus, the ice crystals grow at the expense of the water drop. Since the quantity of supercooled water is far greater than the ice crystals, the crystals can continue to grow. When these crystals melt they can initiate the warm rain process (collision and coalescence) and thus grow to precipitable size drops.

Cloud Seeding

Two methods of seeding are generally used. They are referred to as hygroscopic (warm clouds) and ice phase seeding.

Hygroscopic Seeding

This method is not used very often in seeding experiments. Materials such as salt and ammonium nitrate are dispersed in a cloud. Due to their ability to absorb water vapor, small crystals of these salts may grow large enough by condensation and coalescence to produce rainfall.

Freezing Nuclei Seeding

This method attempts to introduce an agent that will act similar to ice crystals and add "freezing" nuclei to a cloud. Dry ice was originally used, but silver iodide is used today due to its relative ease of storage and dispersal. By introducting freezing nuclei, two effects might occur:

1) The additional nuclei present will stimulate ice crystal growth at the expense of the supercooled water.

2) The rapid freezing introduced into the cloud will release thermal energy, i.e. when water changes state from a liquid to a solid the latent heat of fusion is released. As the cloud is warmed, the density will decrease and the cloud will become more buoyant. This buoyant force is evident as the billowy pattern in cumulus clouds. As the cloud increases in height, the air temperature may become low enough to stimulate ice nuclei and begin the "cold rain" process.

Most likely, the growth of droplets to raindrop size is a combination of both of these effects. The addition of ice nuclei (AgI) may stimulate the growth of droplets and also release additional heat to affect the cloud's dynamic properties.

CLOUD SEEDING DESIGNS

Various cloud seeding designs are used to alleviate problems such as natural rainfall variability, persistance effects and time series problems, as discussed below. By alleviating some of these problems, statistical tests become more meaningful.

It is hoped that this study of the precipitation climatology of Michigan will aid the cloud seeder in designing and evaluating cloud seeding experiments.

Target Only

Originally, evaluation procedures of weather modification projects utilized a "wait-and-see" attitude. One simply seeded and noted any appreciable results. Evidence of any subsequent rainfall increase from seeding was for all intents and purposes impossible to detect. This method of evaluating seeding effects was replaced by the use of areas close to the target for comparison purposes.

Such designs are often used by commercial cloud seeders who are under contract to augment the natural precipitation in a given target area. The area has usually been under adverse weather conditions, such as a prolonged drought. Due to these adverse conditions, the seeders main objective is to increase precipitation rather than conduct a sound statistical experiment. Therefore, their statistical evidence, which oftentimes shows copious precipitation being produced in the target region, is highly questionable.

Many meterologists also consider this method unreliable, due to the effect of the natural variability of precipitation in a given area (Olsen and Woodley, 1975).

Percent of Normal Design

The percent of normal design is based on the use of a historical record for a control. It can be expressed by the following equations: (MacCready, 1952)

$$1. \quad R_T = \left[\sum_{j=1}^{K} Y_{S,j} \Big/ \sum_{j=1}^{K} Y^{*}_{NS,j} \right] \times 100$$

$$2. \quad R_C = \left[\sum_{i=1}^{h} X_{S,j} \Big/ \sum_{j=1}^{h} X^{*}_{NS,i} \right] \times 100$$

In these expressions, R_T and R_C refer to the ratios for the target and control areas, respectively. S and NS are the seed and no-seed periods. The asterisk above Y_{NS} and X_{NS} signify that the no-seed values will be based on the area's historical record.

For example, if the precipitation amounts are totaled for seven days, then R_T would be termed the percent of normal weekly precipitation for the target area T. "The denominator of R_T presents a prediction of the precipitation that would have occurred in T if there has been no treatment (seeding). Hence, the ratio R_T compares mean observed with mean predicted precipitation in an attempt at estimating the treatment effect" (Flueck, 1976). The ratio R_T/R_C would be an estimator of the effect of treatment, and can be used to predict the target area precipitation without the necessity of actually seeding.

Target Control Design

This is one of the principal designs used in weather modification today even though it is by no means the most efficient (Schickedanz and Huff, 1971). This design can be used with random as well as non-random schemes. Principally, two areas are utilized, one which is seeded and one which is never seeded. Sometimes more than one control area may be used. The relationship between the target and control areas can be mathematically described by use of an equation. An example would be the equation

3. $E = A + BX$

where A and B are the regression coefficients.

In the above equation, E represents the calculated precipitation in the target area based upon the precipitation in the control area, X. When this equation is used during seeded periods, the difference of observed and predicted precipitation in the target area can be found. These departures can be statistically tested in order to demonstrate seeding effects.

The best control area is one similar to the target area over the same historic period. High correlation between the two areas is necessary in order to reduce standard error. "The standard error of estimate is the yardstick with which statisticians estimate the likelihood that an observed departure from the historic regression line is only the play of chance. If the standard error is small, even tiny seeding effects can be detected as statistically significant" (McDonald, 1969).

An example of a non-randomized target control regression technique is a study of the Kings River in California (Henderson, 1966). Two rivers, the Merced and the Kern, were used as controls in order to predict the future flow of a third river, the Kings. The correlation coefficient between the control river and the Kings River are given as:

$$4. \quad R^2 = \frac{R_{x1} + R_{x2} - 2RX_1RX_2R_{12}}{1 - R_{12}^2}$$

where X_1 and X_2 refer to the Kern and Merced Rivers, respectively. The calculated correlation coefficient was .978. The study was done originally with the Kern river as a control. However, the evaluated standard error was high. This value was much larger than when the Kern and Merced together were used as controls. For example, the calculated standard error using the Kern River alone was 168.3. Using both rivers, the standard error was 99.3.

A regression equation for the Kern and Merced Rivers can be written in the form:

5. $X = b_o + b_1C_1 + b_2C_2$

where X is the control rivers, and b_o, b_1, and b_2 are regression coefficients, and C_1 and C_2 are actual flow values calculated from the rivers. Using the actual data in the experiment, the resulting regression equation was:

6. X = 1.85 C (Merced) + 1.72 C (Kern) - 124.4

The Merced and Kern Rivers together give a good indication of what the flow would be in the Kings River without seeding. Thus, significant results could be achieved by comparing the seeded Kings River with the two control rivers. In this study, an increase of 6.1% in river flow was found with only a probability of 0.005 that this estimate occurred by chance.

Another experiment involving non-randomization was conducted in Jamaica during 1975. In this experiment, percent of normals were calculated along with predicted precipitation amounts from target-control relationships (Griffith and Brown, 1976). This experiment was conducted as a drought relief program so vigorous statistical tests were not employed. Results were qualitative in nature but seemed to show an increase in the target region.

<u>Randomized Experiments</u>. Randomization means leaving to chance which areas will be seeded and which will not be seeded. In this way one is not biased by knowing factors that will affect the outcome of the experiment. The hope is that

the randomization scheme will give equal weight to seed and no-seed areas. Many variations of this scheme are in use today, but it is still necessary to have the control area as a predictor for the target area and determine this relationship in some manner.

One randomized experiment was initiated at Climax, Colorado in 1960 and continued through 1965 (Grant and Mielke, 1967). The design features included:

1. Randomization between the seed and no-seed samples accomplished by drawing 100 paired slips from a container at the start of each season.
2. The experimental time unit was 24 hours. According to the study this time interval was a compromise that minimizes variations in the physical parameters during an event and is still long enough to lower the noise level (variability) to reasonable values when establishing correlations with upwind controls.
3. The observations of meteorological variables in both seeded and non-seeded cases are made as intensively as possible during all stages of the precipitation process.

A second experiment performed by Electricite' De France utilized a variable time unit (Bernier, 1967). Its features included:

1. A fixed target basin.
2. A dense network of ground generators.
3. A dense network of recording and non-recording gages, both in the target and the comparison area, the performance of which could be continuously and critically watched by those responsible.
4. Randomization of seeding.
5. The definition of the unit period of seeding is accomplished in complete ignorance of whether the unit was seeded or not.

The observational units chosen were the total amount of precipitation per rainy period. The term "rainy" was used to describe a sequence of periods of continuous precipitation in the target and control between two consecutive times of reading on the raingage. During these times there was no precipitation. Not all rainy periods were used, only those passing established criteria.

Other basic randomized experiments have been run in Australia (Smith, 1967) and Arizona (Battan and Kassander, 1967). Recent experiments generally make use of more efficient statistical designs, together with randomization, in an attempt to decrease any possible bias in the experiment.

Crossover Design

This design statistically is more efficient than the target only or the target control designs (Schickedanz and

Huff, 1971). It utilizes two seeding locations, with only one seeded at a time. The selection of which location to seed is made randomly. The most famous experiment utilizing this technique is one initiated during 1961 in Israel (Gabriel, 1967). This randomized experiment involves two areas, North or Center separated by a buffer zone. A fourth area, South, was used for evaluation purposes.

One major area was seeded if the day was designated as rainy. According to Gabriel, a day was defined rainy if there was some precipitation in the buffer zone between the two experimental areas, a zone which will never be seeded.

Each day an average seed/no-seed ratio was calculated as simply the geometric mean of the seed/no-seed ratios for the two areas. Thus, Gabriel's ratio was calculated as:

7. Avg. S/NS ratio = (North S/NS x Center S/NS ratio)

$$= \frac{\text{Avg. daily precipitation in North when seeded}}{\text{Avg. daily precipitation in North when not seeded}} \times \frac{\text{Avg. daily precipitation in Center when seeded}}{\text{Avg. daily precipitation in Center when not seeded}}$$

The randomization technique utilized a random number table for an entire season. Each day was recorded on a control calendar at the commencement of each season.

In this study it was assumed that there was no contamination between the North and Center areas. In a study by Wurtele (1971) the possibility of contamination was investigated. It appears that some contamination was present in this experiment.

Other projects which utilized the crossover design include the Rapid Project in South Dakota (Dennis and Schock, 1971) and a modification project in the Deccan Plateau of India (Krishna et al., 1974).

Other Designs

Many other designs are a variation of the designs discussed above. In the famous Whitetop Experiment in Missouri (Decker, et al., 1971) a "floating target" was employed. This study was conducted during the five-year period 1960-64 in South Central Missouri and North Central Arkansas. The days designated as "seedable" were randomly selected from a list of days where favorable cumulus development was indicated.

The treatment areas were defined as "the smallest reasonable area over which the seeding agent could spread." According to Decker, the "treatment area" was the region over which the silver iodide plume was carried by the prevailing winds at the flying level of the aircraft releasing the seeding material. Thus the target region "spread" across the area under study.

Project Cloud Catcher, an experiment performed in the Northern Great Plains from 1969-71 (Koscielski and Dennis, 1971) was a randomized cloud seeding study aimed at convective clouds in small floating target areas. Originally in 1969 and 1970, the test cases were defined by a grid which extended to 35 nmi. in all directions from a radar facility. In 1971 the study area extended circularly and was defined by the distance and bearing of the center from the radar facility.

Other variations in design tried to improve on the selection of seedable versus non-seedable days. Variables are used which will help distinguish days with high seeding potentials. An example of using these variables (empirical predictors) is in the Florida Area Cumulus Experiment (FACE) (Biondini, et al., 1977). This analysis also employed both a floating and non-floating target.

According to the study, "the primary goal is to estimate, on the basis of observed quantities which are physically independent of seeding treatment, how much rain would have fallen in the total target, floating target and non-floating target, had the seeding treatment been the opposite of what actually occurred." Some predictors used included rainfall in the target area for the one-hour period prior to the first treatment pass (prewetness), the percent of the area within 100 nmi. of the radar covered by echoes at a given time (coverage), the maximum seedability of the one-dimensional model, the number of hours between two given time periods during which there were echoes in the target area, and the speed of echo motion. Thus, complicated predictors could be used to increase the designation of a "seedable" day.

These predictors were used in a regression equation to see if any responses could be predicted. The result is various models which try to explain the variability of the response variable of interest. The primary importance of these predictors is to improve the accuracy and precision of a carefully controlled experiment.

Basic Design Problems

Variability

Large natural variations in physical phenomena affect their predictability and makes the evaluation of modification projects even more difficult. The main problem is that sometimes natural variation is greater than the actual precipitation increase one is looking for. It is the use of a correct design and an efficient statistical method that will diminish the importance of natural variation.

Mathematically, variability can be expressed in terms of the mean square error (MSE) as:

8. $MSE = b^2 + E^2$

where b is the bias (mean error) and E^2 is the variance of the errors.

One problem in addition to natural variability of rainfall, is the error present in rainfall measurement. Olsen and Woodley (1975) have considered both these sources of variability. Some conclusions they reached are as follows:

1. Measurement errors are important, but only up to a certain point. After this point, the effort to create further accuracy is not very fruitful.
2. Natural rain variability is a serious problem. The use of predictors (seedability criteria) is necessary to diminish this inherent variability. Seeding on all days would be a serious mistake.

In a paper presented at the Oklahoma Academy of Science meeting in Oklahoma City, Pybers and Hughes (1973) investigated the effect of "area" variation of rainfall. They found that by using correlation coefficients, "year-to-year variation in precipitation contributes more to the variance statistic than does station-to-station variation during the same one-year intervals." This would also confirm Olsen and Woodley's analyses that measurement errors (usually area affected, rather than time) are less important than the year-to-year natural variability.

In their extensive paper, Schickedanz and Huff (1971) studied various designs and stratifications of meteorological data to try to define the most efficient (in terms of time and sample size) method available for the study of seeding effects. An important point to be made is that studies such as this will ultimately lead to more efficient designs and statistical procedures and thus will lessen the overshadowing problem of natural rainfall variability.

Time Series

Many modification projects rely on a historical period of rainfall. This procedure raises a question: Does the normal amount and distribution of rainfall change in a given location over a period of time? An affirmative answer to this question has profound implications since many studies include a long historical period as a "control" against a seeded target.

As stated above, an important factor in a seeding experiment is a high correlation between the treatment and control areas. If the regression between these areas has changed over a period of years, the correlation of rainfall presently in the target and the control areas would be different than the correlation of a present treatment area with an old "control" area. This can alter the results of a seeding program depending upon the severity of the regression line change with time.

It is through this method that some commercial cloud seeders show positive results from cloud seeding. A cloud seeding program initiated in Michigan in the early 1970's included the 1930's as part of a 30-year historical data base (Krick, 1975). Surely, the rainfall statistics of the "dustbowl" thirties will not agree with today's rainfall statistics. An increase of precipitation was found in the designated target but perhaps this same increase would have occurred without seeding.

Another factor is the problem of an anomalous year. This was investigated in a recent paper by Hobbs and Rangno (1978). They studied a modification project located in the Skagit River Basin of Northwestern Washington. Previous analysis by Hastay and Gladwell (1969) had shown a 15% increase of runoff in the Skagit River during the second year of the project (1964). This was significant at the .005 level. The study conducted by Hobbs and Rangno has shown that an anomalous year was included in the control used, a year in which the .005 level of significance was based. They have further shown that comparison of the Skagit River with two other rivers (that are correlated well) show no significant effects due to seeding.

<u>Persistance</u>

Schickedanz and Huff had found that the crossover design was the most efficient one to use in modification experiments. A problem would arise, however, if some seeding effects still existed in the atmosphere after the seeding had ceased. E. G. Bowen (1966) states that "when seeding is carried out, the effect on rainfall persists or builds up at a certain rate, and then when seeding stops the effect does not stop instantaneously but decays at some finite rate." Bowen, however, says that this finding is not new. In the 1950's Boucher (1956) found occasions where high freezing nucleus counts were found several days after a seeding experiment. Even though this effect might not be of prime concern in all places in the United States, the possibility of it occurring still exists.

The effect of this on cloud seeding experiments is profound. This error would show an apparent decrease in the result of the experiment as time went on. Bowen further states that "the cumulative and decay effects follow a geometric progression, a seeding schedule which is changed on a daily basis, would be more damaging to the end result than if the change had been made on a longer term, for example, by storm periods."

The crossover design would suffer the most from the persistence effect and hence be much less sensitive. Also, the effect of persistence would be difficult to measure due to the decay of the "seeding effect" after seeding has terminated at the same rate in both areas.

A possible candidate for this effect is the Israeli experiment which utilized a crossover design. Gabriel, however, has shown no evidence of this effect occurring (Gabriel et al., 1966). Season-to-season, within season and day-to-day persistence tests all appeared to be negative. However, in a study of the Colorado River Basin Pilot Project in the San Juan Mountains, Rottner et al. (1975) has found possible persistence a problem. In fact, ice nuclei counts two to three orders of magnitude above normal background were found on days following seeded days.

Extra Area Seeding Effects

A potential problem of seeding evaluation experiments is the possibility of a "seeding effect" occurring outside of the designated target region. Many authors have studied this problem and obtained conflicting results. Schickedanz (1974) studying this effect in Illinois concluded that:

1. The distance between precipitation "highs" (maximum in the precipitation pattern) were in the range of those reported in other areas.
2. Urban rain effects occur, but are limited to within 50 miles of a city.

Many theories exist on the reason for these maximums of rain to be displaced (usually downwind) from the target region. Schickedanz (1974) cites three theories. The first is that updrafts are enhanced in the area that is seeded and ice particles are carried upward and outward. These create artificial clouds which seed cumulus clouds downwind of the target region. A second theory states that the enhancement of precipitation is due to increased cloud top heights in a squall line. These influence other clouds along a cold front. A third possibility is increased cloud growth in the seeded region. This growth may set up waves which spread outward and form precipitation maxima.

Another effect investigated by Schickedanz involves the effect of urban areas on precipitation. METROMEX was the first program developed to study the causes of urban rain anomalies. This program was initiated after the discovery of an anomaly of rainfall present at LaPorte, Indiana (Changnon, 1968). A hypothesis for this and other urban rain anomalies was intensively studied by Changnon et al. (1975). Some ongoing studies include ones in St. Louis (Huff and Changnon, 1972; Huff and Vogel, 1978) and a study of the Detroit-Windsor Area (Sanderson and Gorski, 1977).

RAINFALL SIMULATION MODELS

Purpose

In the years of this study, 1949-1971, no weather modification experiments were carried out in Michigan. Modification studies were initiated the following year, 1972, and continued for the next four years. Herein the problem arises: How can one show the distribution of cloud seeding effects based only on five years of data? A study based on these five years alone would be hampered by large variation in natural rainfall between years due in part to the very short time period used.

The purpose of simulation models is that by applying them (with the assumption that naturally falling rain will be increased (decreased) by cloud seeding), we can study the geographic distribution of precipitation using a much larger data base. In this study, 23 years were used.

Various Models

The selection of models is entirely arbitrary. Models are chosen that will try to duplicate (given modern technology) seeding under various conditions. Huff and Changnon (1971) decided on seven different models. The amount of precipitation increase or decrease was dependent upon the quantity of precipitation received in a given 24-hour period.

These are called "variable change" models. Also included were five "static" models. In this case the alteration of precipitation was constant and independent of precipitation amount. Changnon's models are listed in Table 1. Note that Models E and A provide mostly increases throughout the various intervals of rain whereas Models B, C, and X allow both increases and decreases depending upon the quantity of rainfall received.

TABLE 1

VARIABLE-CHANGE AND CONSTANT-CHANGE SEEDING MODELS USED TO MODIFY NATURALLY OCCURRING RAINFALL

Daily rainfall (inches)	Variable percentage change for given model E	A	B	C	X	Y	Z
0.10 or less	150	100	75	50	-50	-75	-100
0.11-0.50	75	50	30	20	-30	-50	- 75
0.51-1.00	30	20	10	0	-10	-30	- 50
Over 1.00	10	0	-10	-20	0	-15	- 30
Constant-change model percentages	40	25	12		-15	-30	

Assumptions

These models are based on rainfall received from convective systems only (cumulus-type rainfall). Since this type of rainfall is most prevalent during the spring, summer, and early fall seasons, the models only apply during this time. Also, since cumulus-type rainfall is of relatively short duration, the models only apply to daily rainfall totals.

Note that in the variable change models (B, C, X) the largest increases occur with the smallest amount of rainfall. This occurs since cloud modification assumes that most cloud systems are not as efficient as they could be. Thus, the smallest rain producers would be the most modifiable.

Another interesting point is the decrease given for rain amounts greater than one inch, in Models B and C. A cloud system producing a large amount of rain would be very efficient. One cloud modification theory suggests that adding additional nuclei will just increase the size of the downwind anvil which is composed almost entirely of crystals. This can decrease the amount of rain that would have fallen naturally (Ross, et al., 1973).

> "In a pioneering work to determine the potential for cloud seeding in Illinois, Changnon and Huff (1972) tested a large number of models to simulate changes in precipitation.
>
> Research workers in other states have used these models in a series of studies similar to ours sponsored by the Bureau of Reclamation (Montana, North Dakota, Oklahoma, South Dakota, Texas, Wyoming). From conversations with these scientists and others having experience in cloud seeding, we found the consensus to be that Model B most nearly approximates the expectations from a well-managed seeding program. Tests with data

> from a few stations in Kansas led us to believe that other models would not add appreciable information." (Bark, 1978)

An important point is that even though Model B adds a large percentage increase for small amounts of precipitation, this quantitively may still be a small amount. This may, however, turn out to be crucial in some drought situations.

Variability: A Problem in Analysis

A significant problem in assessing results with weather modification is the inherent natural variability of the rainfall itself. For example, Huff and Changnon (1971) gave an example using Model A based on their own Illinois data. "The median effect of this model is an increase of 26% over the naturally occurring regional rainfall. However, in a year selected at random, there is a 5% probability of a 42% or more increase in July rainfall, and a similar probability of less than a 14% increase. This variation is due to the temporal variability in the distributional characteristics of daily rainfall upon which the variable-change models operate."

In this paper, the assumption will be that Model B is the best choice for approximating the results obtained in cumulus seeding in the central United States today.

DATA

The selection of stations for this study was made from a list of those published by the Environmental Data Service, National Oceanic and Atmospheric Administration. Those selected had a continuous record of data during the period 1949-1971. This span of years was used due to the relative ease of data retrieval from computer tapes. This period was also considered sufficient to establish normal statistical averages of data.

Editing and Supplementation of Data

The arduous task of editing data took many months to complete. The data was stored on magnetic tape and retrieved via computer programs. Additional computer programs were written to flag both missing data and accumulated precipitation totals.

An accumulated total was caused by an observer being absent for a period in excess of one day and then reading the raingage upon return. Even though this reading would not be totally accurate due to the problem of evaporation, it did serve as an approximate precipitation amount. For example, if an observer was absent for ten days, a total value of precipitation would be observed on the eleventh day.

The total precipitation was then divided up by comparison with surrounding stations. This procedure involved mostly trial and error, based on repeated patterns of precipitation. Geographical distance of stations, proximity to the Great Lakes and elevation were all taken into consideration. As a further guide, the National Climatic Center's estimates of total monthly precipitation were used.

A second problem was data that were completely missing from the record. These proved to be more difficult to estimate due to the lack of any numerical guide. The same procedure of comparison stations was used, however to estimate missing data.

When the task of "cleaning" and editing the data was completed, a computer program was written to sum daily precipitation amounts into weekly intervals. Weekly intervals were used since daily recorded amounts of precipitation can vary even if two stations receive the same amount. For example, if an observer records his precipitation in the evening, the division of precipitation may be different than one who records in the morning. By using seven-day increments this bias will tend to average out and thus the time of observation would not have to be considered in an analysis of precipitation.

Gamma Distribution

The distribution of daily rainfall is highly skewed to the left with the majority of amounts being less than the mean. Thus, a normal distribution would be inappropriate in this case to describe rainfall. The Gamma Distribution has been found to fit skewed rainfall distributions. According to Schickedanz (1969), "This distribution has been used extensively in fitting rainfall distributions by Barger and Thom (1949), Thom and Vestal (1968) and Mooley and Crutcher (1968). Schickedanz (1967), Neman and Scott (1967) and Schickedanz and Decker (1969) have demonstrated its utility in the verification of rainfall modification experiments." More recent papers utilizing this distribution include ones by Olsen (1975), Crow (1978), and Simpson and Woodley (1975). Both the actual rainfall and simulated rainfall were fit with the Gamma Distribution. After determining the distribution parameters, precipitation amounts at the 50% probability level were calculated and used to prepare rainfall distribution maps. All mapping was done with SYMAP* to facilitate handling of the data.

*Graduate School of Design, Harvard University, 1975.

MAP DISCUSSIONS

The climate stations used in the study can be seen in Figure 1. They were well distributed over Michigan and represented the major climatic divisions.

Three maps were produced via SYMAP for each week. The first map was the gamma distribution 50% probability level for actual precipitation. The precipitation values for each station were placed on the map and isohyets were drawn at intervals of 0.1 in.

In the discussion of this map, minimum precipitation amounts are taken to be < 0.40 in. when not specified otherwise. Maximums are taken to be > 0.50 in. when not specified.

A second map produced was the additional precipitation produced by simulating seeding with Model B. The difference in amount of rainfall between the 50% gamma level of actual and simulated rainfall was determined. These values were also mapped. Contour lines were drawn at increments of 0.04 in.

In the map discussions, maximums are taken to be > 0.12 in. when not specified otherwise. Minimums are taken to be < 0.08 in. when not specified.

Figure 1 - Map of Climate Stations Used in Study

A third map produced was the percentage increase of precipitation attributable to Model B. This can be expressed as:

(Model B Precip. - Actual Precip.)/Actual Precip.
X 100

Contour lines were drawn at intervals of 10%.

Maximum values are taken to be > 30% when not specified. Mimimums are taken to be < 20% when not specified.

SPRING SEASON

APRIL

Week 1 (April 1-7)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. The largest amounts of precipitation are found in the southern region with a statewide maximum of 0.71 in. at Hillsdale. The minimums are found in the northeast with a low value of 0.28 in. at Cheboygan. These minimums also extend around Saginaw Bay to the northern Thumb area. Precipitation amounts of 0.4-0.6 in. are found in the Thumb, and extend westward and northwestward toward northwest lower Michigan. To the south of this region amounts increase from 0.5-0.6 in. to 0.6-0.7 in. along the southern area.

Upper Peninsula. The range of precipitation is less extensive than in the Lower Peinsula with amounts from 0.25-0.49 in. However, most of the Upper Peninsula ranges from 0.30-0.40 in.

Model B Percentage Increases

Lower Peninsula. Two principal maximum areas of > 30% increase occur in the northern half from Lake Michigan to Lake Huron. Another area is located in the west central lower region. The southern half consists of scattered small regions of maximums (> 30%) and mimimums (< 20%).

Upper Peninsula. Generally, maximum values of > 30% occur throughout the area. However, a singular value (state's minimum) of 19% is found at Iron Mountain.

Week 2 (April 8-14)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Amounts range from a low of 0.14 in. at Caro in the Thumb, to a high of 0.45 in. at Hillsdale in the south. The only major areas not in the interval of 0.2-0.3 in. are in the southwest (0.3-0.4 in. maximum) and in the area to the south of Saginaw Bay (0.1-0.2 in.). The maximum precipitation amounts occur in the extreme southern Lower Peninsula.

Upper Peninsula. Amounts are almost entirely in the interval of 0.2-0.3 in., with an exception in the south central region (0.1-0.2 in.). The highest precipitation amount in the Upper Peninsula is only 0.30 in. at Bergland Dam.

Model B Percentage Increases

The potential increases from Model B this week are the highest obtainable during the entire study period (April-September). The maximum increase of 48% occurs in the area near Scottville, close to Lake Michigan. A low of 15% occurs in the eastern Upper Peninsula around Dunbar Forest.

Lower Peninsula. Areas of extremely large percentage increase (> 40%) occur in the Thumb, in central lower Michigan, and small areas around Scottville and Mt. Clemens. Some areas of 20-30% increase occur in the southwest along Lake Michigan, and in the northern region. Note that during this week, no values of potential increase are below 20%. Most of the Peninsula is in the range of 30-40%.

Upper Peninsula. The majority of the region lies within the range of 20-40% increase with one singular exception at Dunbar (15%).

Week 3 (April 15-21)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. The pattern of natural rainfall this week is more complicated than the previous two weeks. The variation of rainfall within the Lower Peninsula has changed from a basic north-to-south increase seen in other weeks. While the largest amounts still occur in the south (.76 at Niles), large amounts also occur in the central lower region. Minimums occur in the northeast lower area with a statewide low of 0.32 in. at Cheboygan.

Isohyets of precipitation tend to be longitudinally, rather than latitudinally oriented. Two areas of 0.6-0.7 in. occur in the western and central sections. Maximum values of 0.76 and 0.71 in. occur in these areas, respectively. Proceeding eastward, amounts of 0.5-0.6 in. are the rule. This lowers to 0.4-0.5 in. closer to Lake Huron and Saginaw Bay. Amounts increase again to 0.5-0.6 in. further eastward and drop once again to 0.4-0.5 in the southeast.

Upper Peninsula. The range is from 0.36-0.55 in.

Model B Percentage Increase

Lower Peninsula. Potential maximum increases of more than 30% attributed to Model B are rather small, but exist to the north of Saginaw Bay and in the very northern Lower Peninsula. Other maximum increases occur in the south central lower area and a small region in the southwest, around Kalamazoo. The principal areas of minimum increase occur in a boot-like region in the west central lower division. A statewide minimum value of 15% exists at Hesperia. Other small minimum areas are scattered in the central region.

Upper Peninsula. The range is generally from 20-40% with a statewide maximum of 36% in the central region.

The rest of the state generally lies within the interval of 20-30%.

Week 4 (April 22-28)

Natural Precipitation Patterns - 50% Probability Level

The range of precipitation in the last week of April is much larger than the rest of the month, ranging from 0.30 in. in the central Upper Peninsula to a large 0.95 in. at Eau Clair in the southwest.

Lower Peninsula. The lower precipitation amounts occur in the northern region while the highest amounts occur in the southernmost area. From Saginaw Bay northward, amounts range from 0.5-0.7 in. with a maximum of 0.72 in. at Cadillac in the northwest. Amounts of 0.5-0.7 in. also occur in the central eastern region. A low of 0.47 in. occurs in the Thumb along Saginaw Bay. Amounts of 0.7-0.8 in. occur in the southwest progressing northeastward through a narrow strip to Saginaw Bay. These amounts also exist in the southeast region. Amounts of 0.8-0.9 in. occur in the very southern areas, with the state's maximum of 0.95 in. around Eau Claire.

Upper Peninsula. The range is mostly from 0.4-0.6 in. in the east and west, with some 0.3-0.4 in. amounts in the Keweenaw Peninsula and southward from Grand Marais.

Model B Pencentage Increase

Lower Peninsula. Potential increase ranges from an extremely low 7% at Hesperia, to 31% at Gaylord. The minimum value of 7% is the smallest increase throughout the study period. The only maximum increase above 30% is a very small area around Gaylord, in the north. Areas of minimum increase (10-20%) occur in the southwest and south central regions with an area of extreme minima (< 10%) in the central region along Lake Michigan. This area extends southeastward (10-20% increase) to the west of Grand Ledge.

Smaller minimum areas (10-20%) occur near Saginaw Bay, the eastern Thumb and around Cadillac in the northwest.

Upper Peninsula. Amounts are entirely in the interval of 20-30%.

April Results

Natural Precipitation Patterns - 50% Probability Level

The pattern of natural rainfall is basically the same during weeks 1, 2 and 4. The largest amounts of precipitation appear in the extreme south central or southwestern Lower Peninsula. For example, Hillsdale has the highest value of precipitation during weeks 1 and 2 with values of 0.70 and 0.45 in. respectively. During week 4, a value of 0.95 in. occurs in Eau Claire in the southwest with Hillsdale also being extremely high at 0.90 in.

The maximum amounts during weeks 1, 3 and 4 tend to extend further northward especially close to Lake Michigan. For example, Holland has values of 0.61, 0.60 and 0.82 in. during these three weeks. Week 3 is an exception in that it has an isolated closed contour of precipitation in the range of 0.6-0.7 in. with a maximum value of 0.71 in. close to Lake Michigan. Week 4 differs as large amounts of 0.7-0.8 in. extend in a narrow band to Saginaw Bay.

The Upper Peninsula has no set pattern of precipitation, but generally has amounts similar to those of the northern Lower Peninsula.

Minimums of natural precipitation tended to be in the northern Lower Peninsula and parts of the Upper Peninsula. However, during week 2, the lowest values occurred in the Thumb.

Looking at the percentages of stations above 0.5 in., week 1 has 35%, week 2 has 0%, week 3 has 52% and week 4 has 86%. Thus, heavier precipitation amounts fall toward the end of April, with a minimum occurring during mid-month.

Model B Percentage Increases

Quite a contrast exists between the first and second half of April. The first two weeks have larger percentage increases than the latter half. During week 1, large areas of > 30% increase exist in the northern Lower Peninsula and in the central Lower Peninsula near Lake Michigan. During the second week, a sizeable portion of the state has increases above 30%. During weeks 3 and 4, minimum values come into play. The lowest value of 7% occurs during the fourth week near Lake Michigan.

The sharp contrast between the first and second half of the month in potential increased precipitation is shown below. The percentage of stations above 30 is 37% during week 1, and 66% during week 2. During week 3, the value drops to only 18%, and by the fourth week only 1% of the stations are above 30%.

If one were seeding, there are two things that may be important. The first is the actual water increase; the second is the largest potential for increase without regard to the actual increase of water. This may be important to overcome wintertime deficits and completely refill the soil profile prior to onset of springtime field work.

The largest additional water amounts would result where a high percentage increase and large natural precipitation area overlap. This, however, appears to not occur very often, and usually the opposite takes place. For example, during week 4, 66% of the stations have greater than a 30% increase. On the other hand, 81% of the stations have natural precipitation totals < 0.30 in. During week 4, the opposite occurs. Eighty-six percent of the stations have precipitation totals > 0.50 in., but 99% of the stations have less than a 30% increase.

Model B Additional Precipitation

Week 1. In the Lower Peninsula, the largest additional rainfall (0.16-0.20 in.) would occur in the Hillsdale and Allegan areas. Both of these regions would have increased near 0.19 in.

No major maximum regions occur in the Upper Peninsula, but a small minimum region (0.04-0.08 in.) occurs around Iron Mountain.

Statewide, 65% of the stations are above 0.12 in. with only 1% below 0.08 in.

Week 2. The largest additional rainfalls occur principally in the Hillsdale region of the Lower Peninsula (0.15 in.). Large minimum areas (0.04-0.08 in.) cover the northwestern one-third of the peninsula, the east central region, and a small area in the extreme southwest.

The Upper Peninsula contains increases of only 0.04-0.08 in. with only two exceptions in the far west and a small centrally located region. A statewide minimum value of only 0.03 in. occurs in the vicinity of Dunbar Forest.

Statewide, 48% of the increases are below 0.08 in. with only 4% above 0.12 in.

Week 3. The largest additional rainfalls (0.16-0.20 in.) occur in the extreme southwest section of the Lower Peninsula and a small area around Port Huron along Lake Huron. The statewide maximums of 0.18 in. occurs near both Kalamazoo and Port Huron.

The largest value in the Upper Peninsula occurs in the vicinity of Steuben, with 0.17 in.

Statewide, 70% of the precipitation increases are above 0.12 in. with no values below 0.08 in.

Week 4. Maximum regions from 0.16-0.20 in. occur in the southern half of the Lower Peninsula centrally located in the extreme south and with a second area further north. An area also exists in the extreme eastern Thumb. In the northern half, smaller areas occur in the north central region and along Lake Michigan from Manistee northward to the vicinity of Traverse City. A statewide maximum of 0.19 in. occurs in the vicinity of Hillsdale. An anomolous value of 0.05 in., however, occurs in the vicinity of Hesperia for the state's minimum.

The Upper Peninsula has a small region of 0.12-0.16 in. in the central area with a minimum region (0.04-0.08 in.) in the east central area from Newberry to Grand Marais.

A very large 83% of the values are above 0.12 in. with 28% above 0.16 in.

Looking only at the highest percentages for increasing precipitation, week 2, with many values > 30%, would be the best time to seed whereas week 4 would be the worst.

Week 1

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 2. Precipitation Maps for Week 1 (April 1-7)

Week 2

A

B

C

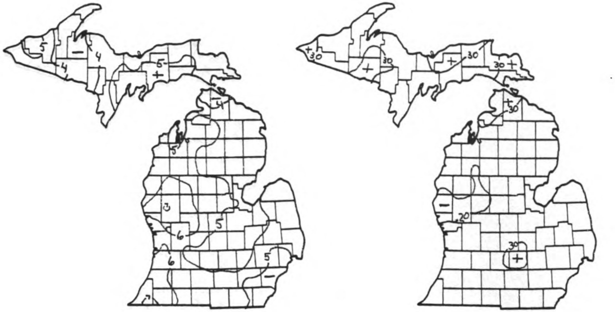
A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 3. Precipitation Maps for Week 2 (April 8-14)

Week 3



A B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 4. Precipitational Maps for Week 3 (April 15-21)

Week 4

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 5. Precipitational Maps for Week 4 (April 22-28)

MAY-EARLY JUNE

Week 5 (April 29-May 5)

Natural Precipitation Pattern - 50% Probability Level

Lower Peninsula. Precipitation amounts decrease dramatically this week from those of the fourth week in April. The total range is from 0.22 to 0.63 in. The Lower Peninsula is generally in the range of 0.30-0.50 in. with two small areas of 0.5-0.6 in. in the very northern tip and in the west central region. What is noticeable this week is the complete change of pattern associated with precipitation amounts. It is almost a complete reversal of patterns that existed in prior weeks.

Amounts of 0.4-0.5 in. cover most of the northern half with amounts of 0.3-0.4 in. in a diagonal band from near Saginaw Bay toward the southwest. Amounts of 0.2-0.3 in. occur in the south central Lower Peninsula northeastward spreading out to the central Thumb region. Exceptions to this are two smaller areas of 0.4-0.5 in. amounts in the extreme southwest lower and south central lower Michigan. Another area of 0.4-0.5 in. exists in the northern Thumb. An area of 0.2-0.3 in. is found to the west of Traverse City.

Upper Peninsula. Amounts generally range from 0.4-0.5 in. with an area of 0.5-0.6 in. (maximum of 0.63 in.) in the west central region around Ishpeming and two smaller areas around Watersmeet in the west and Newberry in the east.

Model B Percentage Increases

Noticeable during this week are very large areas of > 30% increase occurring at 40% of the stations.

Lower Peninsula. A large area of > 30% covers the north. The maximum percentage increase occurs at Thompsonville along Lake Michigan in the western Lower Peninsula. A second sizeable area exists as a Y-shaped region in the central and eastern regions to the south of Saginaw Bay. A smaller area occurs in the southwest from the vicinity of Kalamazoo northeastward. Values of 20-30% increase cover the rest of the Lower Peninsula with a borderline 19% around Lowell.

Upper Peninsula. The region is split in half with values of 20-30% in the western half and most percentages in the 30's in the eastern half. A statewide minimum value of 18% occurs as a singular point in the extreme eastern area which is surrounded by increases in the 30% range.

Week 6 (May 6-12)

Natural Precipitation Patterns - 50% Probability Level

The range this week is from 0.28 to 0.80 in. The minimum of 0.28 in. is found in central Lower Peninsula along Lake Michigan around Scottville. The maximum value of 0.8 in. is found in the western Upper Peninsula around Watersmeet.

Lower Peninsula. This week's pattern is very complicated with an area of 0.3-0.4 in. generally in the northern half of the peninsula increasing to 0.4-0.5 in. amounts in the far northern part. 0.4-0.5 in. amounts encompass the central region with amounts of 0.5-0.6 in. in the southwest and 0.6-0.7 in. amounts in the extreme south central region eastward to the Monroe area.

Upper Peninsula. Amounts are generally from 0.4-0.6 in., with amounts of 0.6-0.7 in. present in the western part, and a minimum region of 0.3-0.4 in. in the extreme south central region and also in the northeast around Grand Marais.

Model B Percentage Increases

When modeling was applied to this week's data, the range was from three maximum values of 32% around West Branch, Scottville and Ludington, to a minimum value of 14% along Lake Michigan around Holland. A large claw-shaped minimum area (< 20%) is seen in the lower half of the Lower Peninsula, from Lake Michigan eastward. Scattered minimum areas are evident in the Upper Peninsula.

What characterizes this week is the fact that 74% of the stations are in the range of 20-30%.

Week 7 (May 13-19)

Natural Precipitation Patterns - 50% Probability Level

Amounts during this week range from a low of 0.27 in. around Ionia to a maximum of 0.68 in. around Rock in the central Upper Peninsula. Approximately half of the region (53%) is in the interval of 0.3-0.4 in.

Lower Peninsula. The Lower Peninsula's precipitation ranges mostly from 0.3-0.4 in. with an area of 0.4-0.5 in. in the southwest (maximum of 0.56 in. around Gull Lake). Another area of precipitation from 0.4-0.6 in. exists in the west central lower division with a maximum of 0.56 in. around Big Rapids.

Upper Peninsula. Amounts are generally much larger than those of the Lower Peninsula ranging from 0.4-0.6 in. However, three areas of maxima (> 0.60 in.) occur. They encircle Rock, the Keweenaw Peninsula, and Manistique.

Model B Percentage Increase

Lower Peninsula. Values range from a singular low of 12% at Benton Harbor (surrounded by values in the 20's) to a high of 40% around Saginaw. The central region is in the 20's and 30's with primarily 20's in the south and also along Lake Michigan and Huron.

Upper Peninsula. Values are almost entirely in the 20's with an area of high teens in the central south.

Statewide, minimums this week are not an important factor.

Week 8 (May 20-26)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. The range of natural precipitation during this week is from 0.23-0.67 in. Larger amounts are in two large areas covering all of the southwest lower Michigan and west central lower Michigan. Precipitation amounts of 0.2-0.4 in. cover the northern Lower Peninsula with amounts of 0.4-0.5 in. over the rest of the area except 0.3-0.4 in. amounts around Saginaw Bay.

Upper Peninsula. This week is quite unusual. Precipitation amounts increase uniformally from east to west with amounts of 0.2-0.3 in. common in the east and 0.6-0.7 in. amounts in the far west. A maximum value of 0.67 in. occurs around Bergland Dam with a minimum of 0.23 at Dunbar in the extreme eastern portion.

Model B Percentage Increases

Almost three-fourths of the state (74%) has potential increases from 20-30%. It ranges from a low of 19% at Beechwood in the Upper Peninsula to a maximum of 36% at Holland, along Lake Michigan in the Lower Peninsula. Scattered areas of 30% are evident in the central Lower Peninsula with a larger area in the northern region.

The eastern Upper Peninsula is generally near 30% while the western Upper Peninsula is generally in the 20's.

Week 9 (May 27-June 2)

Natural Precipitation Patterns - 50% Probability Level

The minimum in the state this week is 0.23 in. at Ann Arbor in the southeast. The high is an unusual 0.93 in. at Manistee along Lake Michigan. Almost half of the state (47%) lies in the interval of 0.4-0.5 in.

Lower Peninsula. In the Lower Peninsula, scattered areas of > 0.50 in. occur mostly in the western half with more sizeable areas of 0.30-0.40 in. amounts in the eastern half. An anomalous area exists at Manistee with a value of 0.93 in.

Upper Peninsula. Precipitation amounts are mostly from 0.40-0.50 in. with an area of 0.60-0.70 in. in the extreme west.

Model B Percentage Increases

In this last week of the spring period, almost 80% (78%) of the stations are in the range of 20-30%. The larger values are in the northern Lower Peninsula with a state maximum of 36% at Vanderbilt. Moderately sized areas of minimum values (< 20%) exist in the south central lower Michigan.

The Upper Peninsula is generally in the 20's with two small areas of 30's in the north central and south regions.

May Results

Natural Precipitation Patterns - 50% Probability Level

During May, north to south increases of precipitation are no longer clear-cut. During week 5, amounts tend to increase further northward in the Lower Peninsula. Large precipitation amounts also occur in the Upper Peninsula with a statewide maximum region of 0.6-0.7 in. in the central region. This is in sharp contrast to amounts between 0.2-0.3 in. in the south central Lower Peninsula.

Week 6 and 7 tend to have closer patterns to that of April in the Lower Peninsula. Amounts of 0.6-0.7 in. occur during week 6 in the south with 0.3-0.4 in. amounts in the northern Lower Peninsula. There is a difference, however, in that amounts increase at the extreme northern Lower Peninsula. The Upper Peninsula again contains large precipitation amounts and, like week 5, has maximum values in the western section.

Week 7 has large amounts in the southwest Lower Peninsula but also contains an area of 0.4-0.6 in. in the west central region. The largest amounts are found again in the central Upper Peninsula.

Week 8 has large amounts in the Lower Peninsula, both in the southwest and west central areas. Although this is similar to that of week 7, the west central region has greatly enlarged. Once again, the highest amounts occur in the western Upper Peninsula.

Week 9 is in sharp contrast to previous weeks. Maximums are scattered in three areas. A small area occurs around Kalamazoo, a second area is located from Traverse City southeastward and a third area is located along Lake Huron from Alpena south to the west of Saginaw Bay. Maximum amounts are located in the western Upper Peninsula.

Minimums vary between weeks. During week 5, minimums were located in east central lower Michigan. Week 6's minimums were in the upper half of the Lower Peninsula (not including the very northern section). Week 7 contained no substantial minimum area in the Lower Peninsula. Week 8 was similar to the month of April with the lowest amounts occurring in the extreme northern Lower Peninsula. Week 9 minimums occurred in the southeast and lower Thumb region.

<u>Model B Percentage Increase</u>

An interesting pattern is evident from weeks 5-9. Week 5 has 40% of the stations at a 30% or greater increase.

<u>Lower Peninsula</u>. Two large maximum areas occur in the north extending southward along Lake Michigan and also in the south central region. During week 6, the maximums in the south are replaced by minimums < 20%. Only two small areas of > 30% are left in the north. Week 7 starts the cycle again with a large potential increase > 30% over most of the central region. Week 8 shows a breakup of this pattern into scattered maximum areas. Week 9 ends the cycle with minimums in the south and smaller maximum areas

in the north. This "cycle" is also evident by noting the percentage of stations above 30% - week 5: 40%; week 6: 6%; week 7: 29%; week 8: 24%; and week 9: 10%.

Upper Peninsula. Important this month in comparison to April is the large precipitation amounts. During four out of the five weeks the state's maximum occurred chiefly in the western half of the Upper Peninsula. Week 9 would have been included if not for an anomalous value in the Lower Peninsula along Lake Michigan. The potential benefits of seeding here are due to the persistant potential increases from 20-35% along with high precipitation amounts.

Model B Additional Precipitation

Week 5. The largest increase in the Lower Peninsula is only 0.16 in. in the vicinity of Baldwin in the central region. A large minimum region (0.04-0.08 in.) occurs southeast from near Detroit to the lower Thumb. Smaller singular minimums are scattered in the southern half.

In the Upper Peninsula, a maximum region of 0.16-0.20 in. occurs in the central area. The statewide maximum of 0.17 in. occurs in this region. A small minimum area is located in the extreme east.

Week 6. The Lower Peninsula has a singular statewide maximum of 0.17 in. near Hillsdale in the extreme south and a singular minimum near Pellston in the extreme north. The value of 0.07 in. at Pellston is a statewide minimum shared with Iron Mountain in the Upper Peninsula.

The Upper Peninsula has its largest increases of 0.12-0.16 in. in the western section with a minimum of 0.07 in. at Iron Mountain.

Week 7. Maximum areas in the Lower Peninsula (0.12-0.16 in.) occur in the south central and central regions. The statewide maximum of 0.15 in. occurs near Big Rapids and is shared by Ironwood in the Upper Peninsula. A singular statewide minimum of 0.05 in. occurs in the vicinity of Benton Harbor.

The Upper Peninsula has maximum regions of 0.12-0.16 in. in the east central area and in the southwest.

Week 8. In the Lower Peninsula small maximum regions (0.16-0.20 in.) occur in the vicinity of Coldwater in the extreme south with a statewide maximum of 0.18 in. in the vicinity of Lake City in the north central area.

In the Upper Peninsula maximum areas of only 0.12-0.16 in. occur in the western half with a minimum region of 0.04-0.8 in. in the extreme east. The statewide minimum of 0.06 in. occurs near Sault Saint Marie.

Week 9. Scattered singular maximums occur in the extreme northern Lower Peninsula and around Manistee along Lake Michigan. A large minimum region exists in the southeast with the statewide minimum of 0.05 in. occurring in the vicinity of Ann Arbor.

The Upper Peninsula has small maximum regions (0.16-(0.20 in.) in the far west and central region with a statewide maximum of 0.19 in. near Grand Marais.

Week 5

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 6. Precipitation Maps for Week 5 (April 29-May 5)

Week 6

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 7. Precipitation Maps for Week 6 (May 6-12)

Week 7

A

B

C

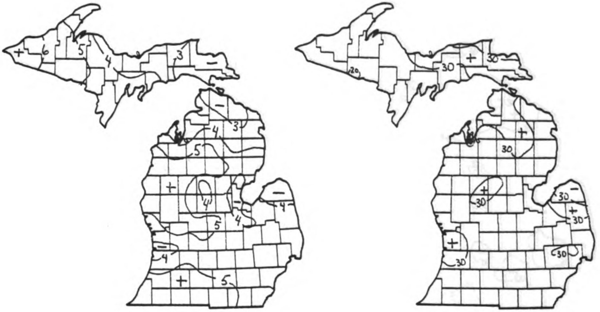
A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 8. Precipitation Maps for Week 7 (May 13-19)

Week 8



A B

C

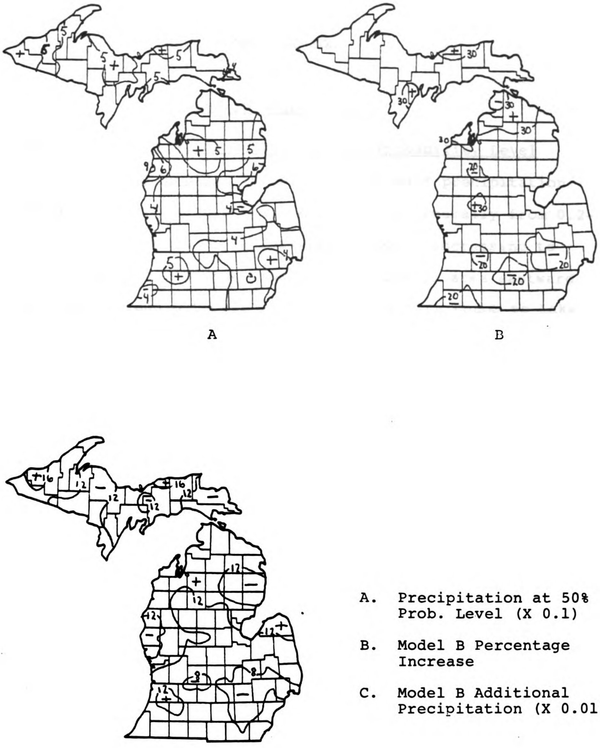
A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 9. Precipitation Maps for Week 8 (May 20-26)

Week 9



A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 10. Precipitation Maps for Week 9 (May 27-June 2)

SUMMER SEASON

JUNE

Week 10 (June 3-9)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. In the southern half precipitation amounts increase southward. Amounts are generally from 0.2-0.3 in. from south of Saginaw Bay westward increasing to 0.3-0.4 in. in a narrow line from the Lowell area eastward and then spread out over most of the eastern thumb to Lake Huron. Amounts generally from 0.4-0.5 in. are found south of this line with the exception of an area of 0.5-0.6 in. (with a maximum of 0.63 around Eaton Rapids) in south central Michigan. From the Hillsdale area westward to Lake Michigan amounts range from 0.5-0.6 in. with a maximum of 0.61 around Three Rivers.

The northern half has a completely different pattern with amounts increasing toward the northeast. The minimum values in the state occur along Lake Michigan from south of Hesperia to north of Thompsonville. Two other small areas are located around East Jordan in the northwest and West Branch in the central area. Proceeding northeastward, amounts increase to 0.2-0.3 in. covering most of the area to Saginaw Bay. Amounts of 0.3-0.4 cover the northeast lower area with a region of 0.4-0.5 in. in the extreme northeastern section.

Upper Peninsula. Amounts generally range from 0.4-0.5 in. An area of 0.5-0.7 in. exists in the central region and the southeast. A minimum area occurs in the extreme eastern end.

Model B Percentage Increases

Approximately two-thirds of the state lies in the interval of 20-30%.

Lower Peninsula. The northwest section has the greatest potential increase where the state maximum of 41% occurs at Kalkaska. A smaller region of > 30% occurs in the eastern section of the northern half. The central Lower Peninsula has scattered areas of > 30% along Lake Michigan in the Hart area, in the central region from around Greenville to north of Alma, and to the south of Saginaw Bay. Southward of a line from Holland and Port Huron, values are much lower (20-30% range) with an area of minimums in the south central region. The state's minimum occurs at Eaton Rapids.

Upper Peninsula. Values are mostly from 20-30% with three areas of > 30% in the extreme east and west and in the central region around Ishpeming.

Week 11 (June 10-16)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Amounts are much greater this week than the previous one. In this week the maximum values increase northward from the central southern border. The statewide maximum value of 0.92 in. is located at Hastings. Proceeding away from this point towards the west and northeast, amounts decrease sharply. Near Lake Michigan amounts are only in the 0.3-0.5 in. range. A small maximum area (0.78 in.) is located around Three Rivers. Another maximum area is located from the central Thumb to southeast lower Michigan with amounts of 0.55-0.72 in. In the northern Thumb precipitation amounts are only from 0.3-0.4 in. In the northern half of the Lower Peninsula amounts are generally from 0.4-0.5 in. but a maximum area of 0.50-0.70 in. occurs around Atlanta. In the extreme northern region amounts are generally from 0.35-0.40 in.

Upper Peninsula. Precipitation patterns are more easily identifiable. Amounts generally increase toward the west. Exceptions to this are an area of 0.6-0.7 in. in the west and an area of 0.5-0.6 in. in the extreme east. A region of maxima is located around Watersmeet and Beechwood, with amounts of 0.84 in. in both locations.

Model B Percentage Increases

Increases are extremely low this month with only 4% of the stations above 30%.

Lower Peninsula. The southern half has mostly values from 10-20% with some values between 20-30% in the southwest, along Lake Michigan and around the Detroit area westward. The statewide minimum is an extremely low value of 8% at Ionia. Only two small areas of > 30% increase exist. One is an area around Saginaw Bay in the Thumb and another is a tiny area in the northwest. A small minimum area exists in the northeast.

Upper Peninsula. Percentage increases range from 20-30% in the eastern half with the exception of a small > 30% area in the extreme east and a < 20% area in the north. The western half has values in the teens with 20's in the western edge.

Week 12 (June 17-23)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. In the southern half precipitation amounts tend to be less in the east. The state's minimum of 0.25 in. occurs at Detroit in the southeast. West of this minimum, 0.4-0.5 in. amounts are the rule with amounts of 0.5-0.7 in. general in the central and west. A maximum value in the southeast of 0.74 in. occurs at Three Rivers. A noted exception to this are values from 0.3-0.5 in. along Lake Michigan around Grand Haven. The northern half has its maximum values along Lake Huron in the east. Minima of 0.3-0.4 in. occur along Lake Michigan from Ludington to

Thompsonville. Amounts of 0.4-0.6 in. occur in the central region and two areas of > 0.6 in. occur along Lake Huron.

Upper Peninsula. General amounts range from 0.5-0.6 in. in the eastern half (except for an area in the 0.4-0.5 in. range in the extreme east) to 0.6-0.8 totals in the western half. Two maximum areas occur around Bergland Dam in the far west and the statewide maximum of 0.88 in. occurs around Rock in the central region. The band of 0.7-0.8 in. generally covers the far west and then extends eastward in a narrow band to the Rock region.

Model B Percentage Increases:

Maximum areas play an insignificant role this week. Minima are numerous with 20% of the stations increasing from 10-20%. They are scattered over most of the Lower Peninsula.

Lower Peninsula. Only 2% of the stations have values > 30%. One small area is located around Mt. Pleasant in the central region while another tiny area is located around Charlevoix in the northwest.

Upper Peninsula. The values are almost entirely from 20-30% with three areas of high teens in the east, central and west.

Week 13 (June 24-30)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Areas of maximum precipitation are scattered throughout the peninsula. They are located in most of the central upper half with values of 0.6-0.8 in. and the central lower half with a maximum of 0.90 in. at Hillsdale in the extreme south central area. Minima cover most of the Thumb and an area near Lake Michigan in the west central region.

Upper Peninsula. Large precipitation amounts occur with four stations having totals in excess of 1.0 in. The state and study period maximum of 1.18 in. occurs at Watersmeet in the southwestern region. Another maximum area occurs in the central area with Rock reporting 1.14 in. No area has an amount < 0.65 in.

Model B Percentage Increases

Minimums are the rule rather than the exception this week as only 5% of the stations have potentials > 30%. Forty-one percent of the stations have increases < 20%.

Lower Peninsula. A maximum area > 30% is located in the Thumb and another small area occurs around St. Charles southwest of Saginaw Bay. Most of south central region and an area in the southwest are < 20%. Smaller minimum areas also occur in the upper half mostly in the center of the state.

Upper Peninsula. Values are mostly from 10-20% in the west and from the teens to the mid-twenties in the east.

June Results

Natural Precipitation Patterns - 50% Probability Level

With the exception of week 10, sizeable areas of maximum precipitation tend to be in the central part of the Lower Peninsula away from Lakes Michigan and Huron. An interesting result during week 13 occurred. The Upper Peninsula stations have considerably larger amounts of precipitation than those of the Lower Peninsula. In two sizeable areas, over one inch of precipitation falls in the central and western sections.

If seeding were initiated based only on the potential for precipitation increase, the month of June would not be recommended. With the exception of week 10, potentials above 30% are rare. During week 10, 25% of the stations have potentials > 30%. The remaining three weeks, however, are quite different. During week 11, only 4% of the stations have potentials > 30%; during week 12, 2 have potentials > 30%; and in week 13, 5% of the stations have potentials > 30%.

Model B Additional Precipitation

Week 10. In the Lower Peninsula an area of maxima (0.12-0.16 in.) covers parts of the extreme south central and southwestern regions. Minimum regions (0.04-0.08 in.) cover most of the central and northwest sections and the eastern Thumb. A statewide minimum of 0.03 in. occurs in the vicinity of West Branch.

The Upper Peninsula has maximum areas of 0.12-0.16 in. in the west, central and extreme eastern regions. The statewide maximum of 0.15 occurs near Ishpeming and Steuben.

Approximately 27% of the stations this week range from 0.04-0.08 in. additional precipitation.

Week 11. In the Lower Peninsula maximum areas of 0.12-0.16 in. cover most of the southern region, the north central area, west central region and the central Thumb. Small singular minima (0.04-0.08) occur in the west central region. These minima are the lowest in the state at 0.07 in.

In the Upper Peninsula the western half has values from 0.12-0.16 in. with the statewide maximum increase of 0.16 in. in the vicinity of Ishpeming.

Week 12. In the Lower Peninsula maximums of 0.12-0.16 in. occur in the southwestern quarter, central region, northern Thumb and the north. A statewide maximum of 0.18 in. occurs in the vicinity of Standish. Minimums of 0.04-0.08 in. occur in the Detroit area.

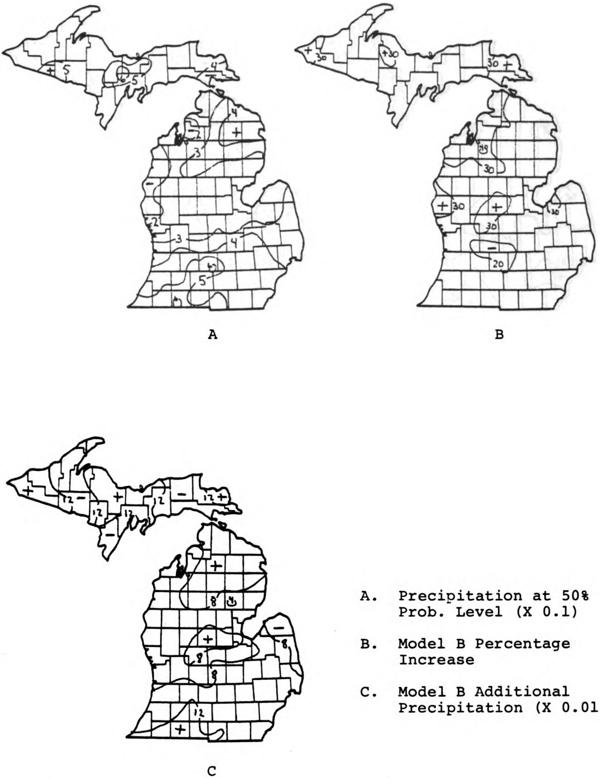
The Upper Peninsula has a large area of maximums (0.16-0.20 in.) in the central region with a statewide maximum of 0.19 in. near Rock. The remainder of the Upper Peninsula is still high (with the exception of the extreme east) at 0.12-0.16 in.

Approximately 14% of the stations have values > 0.16 in. Most of these stations are in the Upper Peninsula.

Week 13. In the Lower Peninsula the principal maximum area is in the far north at 0.12-0.16 in. Smaller regions occur in the extreme south central and southwest sections. Small minimum regions are scattered throughout the peninsula with a statewide minimum of 0.06 in. in the vicinity of Eau Claire in the extreme southwest.

Almost the entire Upper Peninsula has maximum values in excess of 0.12 in. The only exceptions are in the extreme south central region and in the extreme east. Large areas of 0.16-0.20 in. cover the west and central regions. The statewide maximum of 0.19 in. occurs in the vicinity of Manistique in the central region.

Week 10



A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 11. Precipitation Maps for Week 10 (June 3-June 9)

Week 11

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 12. Precipitation Maps for Week 11 (June 10-June 16)

Week 12

A

B

C

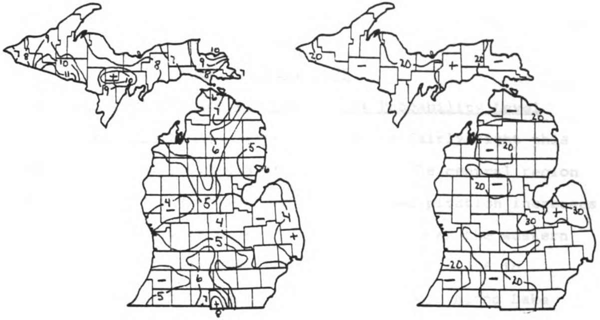
A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 13. Precipitation Maps for Week 12 (June 17-June 23)

Week 13



A B

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

C

Figure 14. Precipitation Maps for Week 13 (June 24-June 30)

JULY

Week 14 (July 1-7)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Precipitation is fairly light this week with mostly 0.2-0.4 in. amounts in the central region away from Lakes Michigan and Huron. Precipitation increases toward the Thumb as 0.2-0.3 in. amounts cover the western Thumb, 0.3-0.4 in. cover the central, and 0.5-0.6 in. amounts occur in the east along Lake Huron. Along Lake Michigan amounts are from 0.4-0.5 in. Precipitation in the upper half is mostly from 0.2-0.3 in. with an area of 0.40-0.45 in. extending from near Standish to Grayling. A maximum amount of 0.53 in. occurs at Grayling. Another small maximum is located around Thompsonville with 0.42 in. The minimum in the state of 0.19 in. is located at Cheboygan in the extreme north.

Upper Peninsula. Precipitation amounts of 0.3-0.4 in. occur in the eastern half, except an area of 0.4-0.5 in. in in the north and Keweenaw Peninsula to 0.5-0.7 in. in the remaining area. The state maximum of 0.74 in. occurs at Rock in the central region.

Model B Percentage Increase

Lower Peninsula. A very interesting pattern sets off the first week in July. Minima in the southern region, maxima in the central region and small scattered areas of both minima in the central region and small scattered areas of both minima and maxima throughout the peninsula. A large maximum area stretches from west of Saginaw Bay northwestward to the shores of Lake Michigan. The statewide maximum of 38% occurs at Mt. Pleasant in the central part of the state. Scattered small maximums occur in the northern half, the lower Thumb, along Saginaw Bay and Lake Michigan. The southern section is characterized by mostly minima < 20%. A very low value of 10% occurs around Benton Harbor along Lake Michigan. A smaller minima area is located around Detroit.

Upper Peninsula. Values are mostly in the 20's but a large area of teens is present in the central region.

Maximums and minima are about evenly distributed statewide with 18% below 20, and 19% below 30.

Week 15 (July 8-14)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. The southern half has a maximum area of 0.5-0.6 in. located in the southwest and south central regions and in the eastern Thumb. A maximum value of 0.51 in. occurs at Howell in the southeast region. This is circularly surrounded by an area of 0.4-0.5 in. and 0.3-0.4 in. The remainder of the lower half has general amounts of 0.4-0.5 in. The upper half has a minimum focal point at Scottville near Lake Michigan. However, a value of 0.65 in.

occurs at Manistee along Lake Michigan. Proceeding from the southwest corner towards the northeast, 0.4-0.5 in. and then amounts of 0.5-0.6 in. are the rule with a maximum of 0.64 in. at Harrison. Continuing northeast amounts increase with a narrow band of 0.4-0.5 in. followed by 0.3-0.4 in. (some 0.2-0.3 in.). In the very northern tip of the Lower Peninsula an area of 0.2-0.3 in. is present.

Upper Peninsula. Amounts range from 0.2-0.4 in. in the eastern half with a anamolous value of 0.8 in. at Detour along Lake Huron. The western half generally has amounts increasing toward the west with the maximum value of 0.79 in. at Watersmeet.

Model B Percentage Increase

This week is by far a week of minimum percentage increase. Forty-two percent of the stations are < 20. These cover a sizeable area of the Lower Peninsula from the northwest to the southeast. An interesting "gap" occurs in the middle of the minimum region in the southern half. In that area values are from 20-30%. This hole ranges from south central to extreme southeast Michigan. Other areas of 20-30% occur in the extreme southwest, most of the Thumb, the west central area and a good portion of the north. Two tiny maximum areas occur around Scottville along Lake Michigan and at Benton Harbor and also along the lake in the southwest.

The Upper Peninsula consists of teens in the west (a small area of mid-twenties in the extreme west) and twenties in the central and east. A moderately sized maximum area of thirties occurs in the central eastern region.

<u>Week 16 (July 15-21)</u>

<u>Natural Precipitation Patterns - 50% Probability Level</u>

<u>Lower Peninsula</u>. The upper half of the Lower Peninsula contains the statewide maximum of 0.79 in. at Mio. This is surrounded by an area of 0.6-0.7 in. and then a comma-shaped area of 0.5-0.6 in. Two areas of 0.3-0.4 in. exist. One is along central Lake Michigan and the other is in the extreme northwest. The remainder of the upper half lies in the range from 0.4 to 0.5 in.

The lower half has a maximum of 0.6-0.7 in. in the south central region and a smaller area in the extreme southwest. The remaining southern area ranges from 0.4-0.6 in. northward toward Saginaw Bay and 0.3-0.4 in amounts occur near Lake Michigan (0.25 in. minimum at Kent City). Amounts of 0.4-0.5 in. occur in the central region. The Thumb area amounts increase northward. Amounts of 0.2-0.4 in. occur in the south and 0.5-0.6 in. in the central with 0.6-0.7 in. in the northern Thumb.

<u>Upper Peninsula</u>. The east has a centrally located area of 0.5-0.6 in. "sandwiched" by 0.4-0.5 amounts on both sides. The western half has a centrally located area of 0.6-0.7 also "sandwiched" by 0.5-0.6 in. on both sides.

Model B Percentage Increases

This week matches the previous one with 42% of the stations having increases below 20%.

Lower Peninsula. The minimum areas are broken up. Two sizeable areas exist in the lower half. Most of the south is covered by minimums with the exception of a tongue in the southeast. Another area occurs in the central and northern Thumb extending westward to the west of Saginaw Bay. A smaller area is found in the western section of the state near Lake Michigan.

In the upper half, two areas are centrally located with a smaller third area in the northeast. The minimum in the state occurs at Muskegon along Lake Michigan. Maximums are insignificant with only two tiny areas at Detroit and Cheboygan.

Upper Peninsula. Values are almost entirely in the 20-30% range with three small areas of minima in the extreme east, central, and around Beechwood in the southwest.

Week 17 (July 22-28)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Large precipitation amounts are located in the south central region. Hillsdale has the maximum with an amount of 0.91 in. Northwest from Hillsdale amounts decrease to 0.3-0.4 in. near Lake Michigan. The eastern region consists of amounts from 0.3-0.4 in. with 0.2-0.3 in. in the northern Thumb. An isolated maximum of

0.63 in. is found at Detroit. The upper half consists of a maximum of 0.63 in. around Big Rapids. Two areas of 0.3-0.4 in. amounts occur along Lake Michigan with a smaller area along Lake Huron. The remainder of the northern half ranges generally from 0.4-0.5 in. with a tongue of 0.5-0.6 in. in the north (maximum of 0.63 in. at Cheboygan).

Upper Peninsula. The eastern half amounts increase toward the west with 0.4-0.5 in. in the east and 0.5-0.6 in. in the central area. A maximum of 0.75 in. occurs at Rock surrounded by 0.6-0.7 in. and 0.5-0.6 in. amounts with an area of 0.4-0.5 in. around Iron Mountain in the south. Amounts of 0.7-0.9 in. cover the western section with two maxima of 0.91 in. located at Ironwood and Beechwood.

Model B Percentage Increases

Once again minimum values cover a large portion of the state with 40% of the stations having < 20% increase.

Lower Peninsula. Minimum values in the Lower Peninsula are split apart. Two large areas exist, one in the southwest and extreme south central region and another covering most of the north. The central region is composed mostly of values between 20 and 30%. Three areas of maxima and minima exist, however. Two small maxima occur in the northern Thumb and around the Pontiac area. A tiny maximum area occurs at Kent City in the western part of the state. One area of minima occurs from Hesperia to Big Rapids and two other tiny areas are located at Detroit and around Flint.

The maximum value in the state occurs along Saginaw Bay at Sebewaing.

Upper Peninsula. Increases in the teens cover the western half and twenties cover the eastern half. Exceptions to this are an area of teens in the extreme east and an area in the 20's from Beechwood to the south of Iron Mountain. Also, an area of 20's occurs in the central region.

Week 18 (July 29-August 4)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. A maximum in the Lower Peninsula of 0.7 in. is located at Three Rivers. Amounts from 0.5-0.7 in. surround this maximum. Weekly totals of 0.5-0.6 in. are also located in the Detroit area and also the northern Thumb. Amounts of 0.3-0.5 in. cover the remaining areas. The upper half has a maximum of 0.69 in. Amounts of 0.4-0.5 in. cover the northern section (with an area of 0.3-0.4 in. in the northeast) and 0.5-0.6 in. amounts generally cover the remaining area.

Upper Peninsula. The range is mostly from 0.5-0.7 in. with 0.4-0.5 in. in the extreme east. In the western half, 0.6-0.7 in. amounts are centrally located surrounded by 0.7-0.9 in. amounts on both sides. The statewide maximum of 0.93 in. is located at Escanaba in the south central region.

Model B Percentage Increase

Increases in the teens are the rule again the last week of July. The number 42 repeats itself again with 42% of the stations having less than 20% increases. Areas of maxima compromise only 2% of the stations.

Lower Peninsula. This time the pattern has changed so that values less than 20% cover the western half of the lower pensinula. The only areas in the eastern half less than 20% are an area around Flint, an area in the northern Thumb and to the west of Saginaw Bay. An area of 20's, however, occurs in the west central region and also in the northern region. The low in the state, 12%, occurs at Baldwin in the west central region.

Two maximum areas exist in the south central region. One is around Jackson and a tiny area is around Battle Creek. The maximum in the state, 33%, occurs in these two locations. The remainder of the Lower Peninsula is in the 20% range.

Upper Peninsula. The peninsula is composed mostly of the 20's in the east (except high teens in the extreme east) and teens in the central and west. An area of 20's is located in the Beechwood-Crystal Falls area.

July Results

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Natural precipitation patterns are quite variable in the Lower Peninsula. Week 14 is similar to patterns in the early spring as lower precipitation amounts are found in the very northern section. Week 15's minimums occur in the northeast, east central and southeast. Maximums occur in the southwest during week 14 and in both the south central and northwest sections of the state during week 15. By week 15, minimum amounts are located all along Lake Michigan and in the lower Thumb along Lake Huron. The maximum are clustered in two areas in the south central and the north central region. During week 17 amounts substantially increase and the maximums are located in the south central region. Week 18's largest amounts are similar to week 15 in that areas exist both in the south and north.

Upper Peninsula. Values here are more consistent than the Lower Peninsula. Overall, larger precipitation amounts fall in the west with lower amounts in the east. This has been a consistent pattern in the Upper Peninsula throughout July.

Model B Percentage Increases

Percentage increases this month are the lowest in the study. Based upon these alone, seeding would not be very productive. Other than during week 14, maximums make no significant mark throughout the state.

An interesting pattern is seen for weeks 14-18 in the Lower Peninsula. During week 14 the minimum area is confined to the southern region. By week 15 minima covers a good portion of the peninsula. During week 15 the minima tend to break apart but still exist in all sections of the peninsula. At week 17 the minima split apart with a major area in the north and south. During week 18 minima recombine but are limited primarily to the western half of the peninsula.

Model B Additional Precipitation

Week 14. Scattered maximum areas (0.12-0.16 in.) occur in the Lower Peninsula in the south central, southwest, west central, eastern Thumb and north central regions. Scattered minimum areas also occur throughout the peninsula with the largest area occurring in the northern half. However, a statewide minimum of 0.03 in. occurs in the vicinity of Benton Harbor.

The Upper Peninsula has an area of maximum (0.12-0.16 in.) in the west with the statewide maximum of 0.15 in. occurring near Ironwood. A small minimum area (0.04-0.08 in.) occurs near Grand Marais.

Week 15. Maximum regions in the Lower Peninsula are scattered throughout the southern half with a small singular region in the northern half. Minimums (0.04-0.08 in.), however, cover much larger areas with the largest areas occurring from central Michigan to the lower Thumb and in the far north.

The Upper Peninsula has a large maximum region (0.12-0.16 in.) in the southwest with smaller areas in the central region. Minima occur in the northeast and extreme east with the statewide minimum of 0.03 in. in the vicinity of Detour.

Week 16. In the Lower Peninsula maximum (0.12-0.16 in.) areas are located in the south central and the northeast. A fairly large minimum region occurs in the west central region with a statewide minimum of 0.04 in. in the vicinity of Muskegon. Other scattered maximums and minimums occur throughout the peninsula.

The Upper Peninsula has a maximum region of 0.12-0.16 in. in most of the west with statewide maxima near 0.15 in. in the vicinity of Bergland Dam, Beechwood, and Iron Mountain.

Week 17. Scattered maximum regions of 0.12-0.16 in. cover sections of the southern area east of Three Rivers. Minimums (0.04-0.08 in.) cover almost the entire Lake Michigan shoreline. They also extend in a narrow band to the Saginaw Bay regions and also in the northeast. The statewide minimum of 0.03 in. occurs in the vicinity of Traverse City.

The Upper Peninsula has a large area covered by 0.12-0.16 increases with the exception of the south central and the northeast regions. A small minimum region (0.04-0.08 in.) exists in the extreme east.

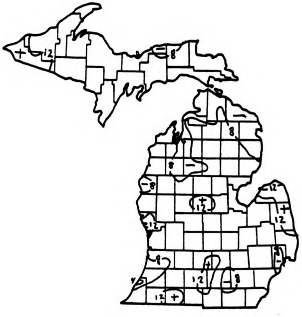
Week 18. Maximum regions in the Lower Peninsula (0.12-0.16 in.) are scattered throughout the lower half with the largest region in the southeast. This maximum area exists in the north central region. Minimums are scattered throughout the Lower Peninsula with the largest area in the west central region. The statewide minimum of 0.06 in. occurs near Holland along Lake Michigan and Bay City along Saginaw Bay.

The Upper Peninsula is covered by maxima from 0.12-0.16 in. except isolated areas in the north, east and west. The statewide maximum value of 0.16 in. occurs in the vicinity of Rock.

Week 14

A

B



C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 15. Precipitation Maps for Week 14 (July 1-July 7)

Week 15

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 16. Precipitation Maps for Week 15 (July 8-July 14)

Week 16

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 17. Precipitation Maps for Week 16 (July 15-July 21)

Week 17

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

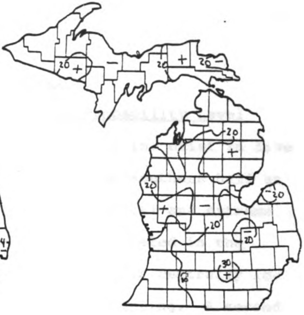
B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

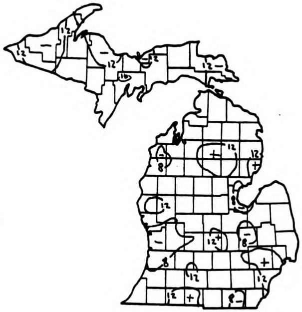
Figure 18. Precipitation Maps for Week 17 (July 22-July 28)

Week 18

A



B



C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 19. Precipitation Maps for Week 18 (July 29-August 4)

AUGUST

Week 19 (August 5-11)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Areas from 0.5-0.6 in. exist in five locations of the Lower Peninsula. In the southern half an area of 0.5-0.6 in. is located in the central and extreme southwestern regions. A second area is located in the southeast. In the northern half one area is centrally locatted around a maximum of 0.64 in. at Grayling. A second area is located in the northeast near Lake Huron and a smaller third area is located near Lake Michigan around Thompsonville. Areas of 0.3-0.4 in. precipitation amounts cover a large portion of the west central region and in the Thumb westward along Saginaw Bay. Another sizeable area is located along Lake Huron in the East Tawas-Mio area. Other smaller areas are scattered throughout the peninsula. Amounts of 0.4-0.5 in. generally cover the remainder of the peninsula.

Upper Peninsula. The eastern three-quarters generally are covered by amounts from 0.4-0.5 in. Exceptions to this are two small areas of 0.3-0.4 in. in the extreme east and in the north around Grand Marais. A third area is located to the south of Escanaba in the central region. An area of 0.5-0.6 in. is located around Newberry in the east.

The western one-quarter contains much higher precipitation amounts with a narrow band between 0.5-0.7 in. and a large area of 0.7-0.8 in. The statewide maximum of 0.82 in. is located at Ironwood in the extreme west.

Model B Percentage Increases

Thirty-one percent of the stations have values less than 20%.

Lower Peninsula. Minimums still cover the Lower Peninsula but are less widespread than those of July. A large area of minima exists in the southeast with a smaller area in the extreme southwest. Two other areas are located in the north central area and northwest along Lake Michigan. Other tiny scattered areas are located in the lower half. Four small maximum areas are located in the extreme south central region, along Saginaw Bay, and in west Michigan in the central area.

Upper Peninsula. Two areas of teens occur. One is located in the east, and the other in the western one-third. The rest of the state ranges from 20-30%.

Week 20 August 12-18

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. The lower half consists of precipitation amounts from 0.3-0.4 in. Three small areas of 0.4-0.5 in. occur in the lower Thumb and two areas in the central region. A sizeable area of 0.2-0.3 in. exists in the south central region eastward toward Detroit. In the upper half amounts are mostly from 0.2-0.3 in. with an area of 0.3-0.4 in. along Lake Huron and a small area of teens near East Jordan.

Upper Peninsula. The eastern half has amounts increasing toward the west with 0.2-0.3 in. in the east, 0.3-0.4 in. further west, and 0.4-0.5 in the central region. The western half consists of amounts from 0.2-0.4 in. with 0.3-0.4 in. amounts covering most of the western quarter.

Model B Percentage Increases

Lower Peninsula. This week is characterized by disconnected minimums and maximums in the Lower Pensinsula. Approximately half of the northern half consists of percentages above 30%. Other areas occur in the southwest, west central, and south central regions. A small area exists in the Thumb and another tiny area along Lake Huron.

Minimums cover two prime areas, one in the southeast and an area in central Michigan. Other tiny areas of minima are scattered throughout the peninsula, in the eastern Thumb, central region, along Lake Michigan and in the extreme north.

Upper Peninsula. Amounts are almost entirely in the 20's with a moderately sized area above 30 in the west central region and in the extreme southwest.

Overall, 63% of the stations lie in the interval of 20-30%.

Week 21 (August 19-25)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. In the Lower Peninsula, an area of 0.4-0.5 in. covers the central region south of Saginaw Bay. Within this region two maximum areas of 0.5-0.6 in. occur. Another area of 0.4-0.5 in. is located in the southeast. Embedded in this is a small area of 0.5-0.6 in. with a maximum of 0.62 in. at Willis. Two other areas of 0.4-0.5 in. amounts are located in the northwest Thumb near Saginaw Bay and in the lower eastern Thumb. In the upper half, 0.4-0.5 in. totals cover a good portion of the northeast with a small area of 0.5-0.6 located in the vicinity of Mio. Otherwise, totals of 0.3-0.4 in. cover the remainder of the Lower Peninsula with the exception of an area in the southwest, a small area in the west central region along Lake Michigan, and an area in the north central region in the vicinity of Harrison. In these areas, amounts are from 0.2-0.3 in. A singular area at Ann Arbor has the state's minimum of 0.21 in.

Upper Peninsula. Amounts of 0.5-0.6 in. occur in the east. In the south central area the statewide maximum of 0.72 in. occurs at Iron Mountain. This is surrounded by values from 0.4-0.7 in. Amounts of 0.5-0.7 occur in the far west with 0.4-0.5 amounts the rule over the remaining central region. A small area of 0.5-0.6 in. occurs in the north central area in the vicinity of Munising.

Model B Percentage Increases

The Lower Peninsula again consists of maximum and minimum values. However, 67% of the stations range in the 20's. Areas of minimum are located in the south central and southeast sections along with a smaller area in the extreme southwest. Other small areas are located in the central region with a tiny area along Lake Michigan at Holland. The state's minimum of 13% occurs at Coldwater in the south.

Between the areas of minima in the south is a small area of maxima located from Kalamazoo to Allegan in the southwest. Another moderately sized maximum is located in the west central region along Lake Michigan. A third area stretches from northwest of Traverse City to the Harrison area in the northwest section of the Lower Peninsula. Two other tiny areas occur at Manistee at Lake Michigan and at Gaylord in the north central area.

The Upper Peninsula is dominated by the 20's with an area of teens in the northeast and in the south central areas.

Week 22 (August 26-Sept. 1

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Amounts generally increase this week. The lowest amounts of precipitation during this week are found in the south. Amounts of 0.3-0.4 in. cover the south central and southwestern sections with the exception of right along Lake Michigan where 0.2-0.3 in. amounts occur.

The state's minimum of 0.15 in. occurs around Benton Harbor near Lake Michigan. The southeast also has amounts from 0.2-0.3 in. Proceeding northward, 0.4-0.5 in. amounts are the rule in the west and central regions with 0.5-0.7 in. amounts in the lower Thumb and along Lake Michigan. A Lower Peninsula maximum of 0.76 in. occurs at Alma in the central region. North of Saginaw Bay, 0.5-0.6 in. amounts are general with an area of 0.4-0.5 in. in the west central region and an area of 0.6-0.7 in. in the northwest.

Upper Peninsula. Two statewide maximums of 0.83 in. occur. One is in the extreme west around Ironwood and another is centrally located around Rock. Between these two maxima, amounts range from 0.5-0.8 in. except for a large area in the north and in the Keweenaw Peninsula where amounts range from 0.4-0.5 in. In the eastern half, a maximum of 0.76 in. occurs at Manistique surrounded by amounts from 0.6-0.7 in. The remaining sections range generally from 0.4-0.6 in.

Model B Percentage Increases

Lower Peninsula. Minimums dominate this week. A large minimum area stretches from the central region west of Saginaw Bay southeastward to the lower Thumb. Other moderately sized areas occur in the northern Thumb and the south central region. Two other areas occur in the north. One is located in a narrow band along Lake Huron and the other is to the north and east of Traverse City. Four tiny areas occur in the southwest and central regions along Lake Michigan at Muskegan and in the north central region around Vanderbilt. Only one sizeable area of maximum occurs in the southwestern part of the peninsula. Three tiny areas occur at Benton Harbor and Scottville along Lake Michigan and at Hillsdale in the extreme south central region. The remaining areas range from 20-30% increase.

Upper Peninsula. The percentage increase is mostly from 20-30% with an area of teens in the far west, central and a small area around Manistique in the south central region.

August Results

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. What is interesting this month is the large contrast of natural precipitation between the second and fourth weeks. This is evident as we compare stations in each week:

Week 19: 29% are greater than 0.5 in. and 70% are greater than 0.40 in.

Week 20: 1% are greater than 0.5 in. and 13% are greater than 0.40 in.

Week 21: 20% are greater than 0.4 in. and 52% are greater than 0.40 in.

Week 22: 59% are greater than 0.5 in. and 82% are greater than 0.40 in.

From the above, we can infer a precipitation climatology in the state. The second week of August is an extremely dry time of year. On the other hand, during late August much larger amounts of precipitation fall.

The patterns of precipitation change drastically. During week 19 in the Lower Peninsula the heaviest precipitation falls in the south with a more moderate area in the north central region. By week 20 the Lower Peninsula is virtually split at Saginaw Bay with generally 0.3-0.4 in. amounts in the south (except an area of 0.2-0.3 in. in the south central and southeast regions) and 0.2-0.3 in. in the northern half. During week 21 the largest area of heavy precipitation are now in the central area of the pensinsula with a smaller region in the southeast. There is also a maximum in the northeast. By week 22 higher amounts are throughout the Lower Peninsula with the exception of the south.

Upper Peninsula. During week 19, as in the previous month, the heaviest precipitation falls in the western region. Week 20 has higher amounts in the central area but generally the entire peninsula has low precipitation amounts. During week 21, heavy precipitation occurs in all sections - west, central and east.

Model B Percentage Increase

While minimums this month still play a major role in the state's pattern, they do so to a lesser degree. During week 19 31% of the stations have increases less than 20%. The largest minimum areas tend to occur in the central lower half and the southeast. No large areas occur in the north. During weeks 19 and 22 minimum values occur in the north and south. Week 19 minimums occur principally in the southeast, north central and a smaller area in the northwest. Week 22 has a large minimum region from west of Saginaw Bay to the lower Thumb and another area in the northwest and northeast.

Maximums appear this month with greater area coverage, unlike the previous month. This is the most evident during week 20 where 25% of the values are greater than 30%. In this week the principal maximum regions are found in the north with other moderate areas in the west central and south central regions. Week 21 has some maximum areas in the northwest, west central and southwest, but only 13% are over 30.

Minimums in the Lower Peninsula still have a dominant role with the exception of week 20. Generally they cover less area than in the month of July. After week 19 the eastern half has larger areas of minimum increase less than 20% than does the western half.

<u>Model B Additional Precipitation</u>

<u>Week 19</u>. The only major maximum region in the Lower Peninsula occurs in the south central region with a statewide maximum of 0.17 in. in the vicinity of Hillsdale. A small maximum region occurs in the southeast. Minimum areas (0.04-0.08 in.) are more numerous with the largest area in

the west central region. Other areas occur in the north central and northeast regions. The statewide minimum of 0.04 in. occurs in the vicinity of Harrison.

The Upper Peninsula has maximum areas of 0.12-0.16 in. in the west and central regions.

Week 20. Minimums of 0.04-0.08 in. cover a large portion of the northern half of the Lower Peninsula except in the north, east and a smaller area in the central region. The lower half has increases from 0.04-0.08 in. except for a large section of the southwest. A maximum area of 0.12 in. occurs in the south central region. The statewide minimum of 0.04 in. occurs in many locations of the Lower Peninsula.

The Upper Peninsula has small scattered maximum areas (0.12-0.16 in.) in the central and far western areas. Minimums (0.04-0.08 in.) occur in a large portion of the northwest region and in the far east.

About 40% of the stations have increases ranging from 0.04-0.08 in.

Week 21. Maximums (0.12-0.16 in.) are virtually insignificant in the Lower Peninsula with scattered areas in the central part of the peninsula. Minimums (0.04-0.08 in.) cover a large part of the south, an area in the eastern Thumb, north central region and other smaller scattered regions.

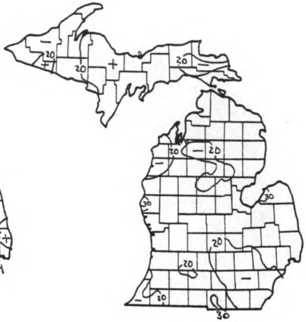
The Upper Peninsula has a large area of maximums in the western half (except an area in the southwest) with a statewide maximum of 0.17 in. in the vicinity of Bergland Dam. Another thin area is centrally located.

Week 22. Maximums (0.12-0.16 in.) cover a large area from the west central Lower Peninsula to the north central region. The statewide maximum of 0.18 in. occurs in the vicinity of Atlanta in the northeast. Another area occurs in the central Thumb with smaller scattered regions over the peninsula. Minimum regions occur principally in the extreme southwest and southeast regions with a statewide minimum of 0.05 in. in the vicinity of Adrian in the southeast and Benton Harbor in the southwest.

The Upper Peninsula is almost entirely from 0.12-0.16 in. except an area in the north central region and a smaller area in the west.

Week 19

A



B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 20. Precipitation Maps for Week 19 (August 5-August 11)

Week 20

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 21. Precipitation Maps for Week 20 (August 12-August 18)

Week 21

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

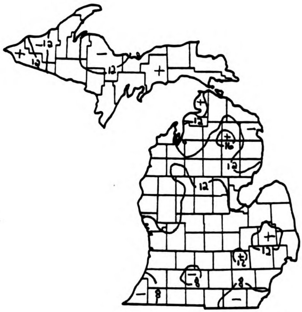
C. Model B Additional Precipitation (X 0.01)

Figure 22. Precipitation Maps for Week 21 (August 19-August 25)

Week 22

A

B



C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 23. Precipitation Maps for Week 22 (August 26-September 1)

SUMMER PRECIPITATION
(WEEKS 10-22)

Natural Precipitation Patterns - 50% Probability Level Week 22 - 50% Probability Level Week 10

Lower Peninsula. In the Lower Peninsula larger amounts of precipitation fall in two areas and tend to be higher than the surrounding regions during the summer season. These areas are the extreme southwest and south central region, and the central northern region. In these two regions, precipitation amounts are in excess of 10.0 in. However, an area of generally larger amounts covers a large area of the south central region. A singular maximum of 9.3 in. occurs at Gladwin in the central region west of Saginaw Bay.

Minimums cover four separate areas. This includes the area from Detroit northwest to around Pontiac in the lower Thumb. A second area occurs mainly to the southwest of Saginaw Bay. A third region covers an area in the west central region along Lake Michigan. A fourth minimum region covers the extreme northern Lower Peninsula. Amounts from 8.0-9.0 in. cover the remaining peninsula.

Upper Peninsula. Larger amounts of precipitation fall in the Upper Peninsula than in the Lower Peninsula. The lowest amount is only 8.0 in. around Detour in the extreme east. Amounts increase toward the west with the highest values occurring in the far western areas and a smaller region in the central section. The state's maximum of 11.8 in. occurs at Bergland Dam in the western part of the Upper Peninsula. Over half (56%) of the stations have amounts from 8.0-9.0 in.

Model B Precipitation Increase

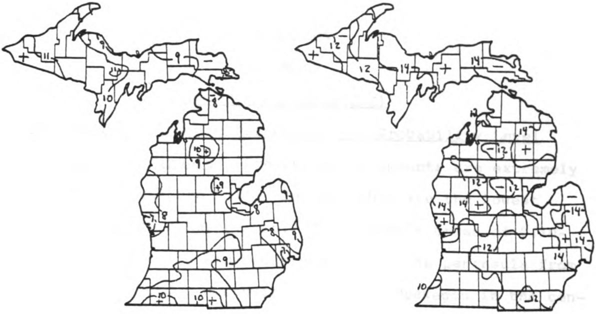
In the Lower Peninsula areas of precipitation increase greater than 1.3 in. are confined to the extreme south central region around Hillsdale with a value of 1.3 in. and the northeast section of the peninsula, also with an area of 1.3 in. A smaller maximum region greater than 1.2 in. occurs in the central and lower Thumb with another area in the central north around Houghton Lake. A large minimum area less than 1.0 in. stretches from the Benton Harbor area to north of Kent City along Lake Michigan. Another area is located in the central region from Ionia northeast to around Alma. A small area occurs around Harrison in the lower north central region.

The Upper Peninsula would yield the most water in the state. Amounts are lower in the extreme east but still do not drop below 1.1 in. The highest additional precipitation amounts would be obtained in the western half with a maximum value of greater than 1.5 in. in the extreme west and in the central region around Ishpeming.

What can also be seen from this map are areas that would generally have the same increased amounts of precipitation. These would serve as good areas for seeding experiments as one location would be correlated with a surrounding area. An example of this would be a good portion of south central Michigan. Most values here are consistent at a 1.1 in. level.

Poorer experimental areas would occur in the north central area as amounts tend to increase and then decrease northward across the state. In these areas, a high correlation would not exist between areas and statistical results would hence be less powerful.

SUMMER PRECIPITATION



A B

C

A. Precipitation at 50% Prob. Level

B. Model B Percentage Increase

C. Model B Additional Precipitation

Figure 24. Cumulative Summer Precipitation Maps (Weeks 10-22)

FALL SEASON

SEPTEMBER

Week 23 (September 2-8)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. Precipitation amounts are extremely low in the southern half. In fact they are the lowest amounts in the study period. Two sizeable areas of 0.10-0.20 in. cover the southwest section of the peninsula from the Indiana border northward to around Muskegon in the central region and as far east as Hastings. The state minimum occurs at Allegan in the southwest. Another large area covers the lower Thumb and part of the southeast.

Smaller areas are located around Jackson in the south central region, around Willis in the southeast, and around Hesperia in the west central region. The upper half has larger amounts of precipitation than the lower half with 0.3-0.4 in. amount occurring in the central region and 0.4-0.5 in. amounts cover the north with an area of 0.5-0.6 in. in the extreme northwest.

Upper Peninsula. Zero point five to 0.7 in. amounts cover almost all of the peninsula. A statewide maximum of 0.73 in. occurs around Munising in the north central region. Some 0.4-0.5 in. amounts cover the south central region.

Model B Percentage Increases

Lower Peninsula. A very interesting pattern occurs during this first week of September. All of the maximum regions (with the exception of a small region in the far north) occur in the lower half. In fact, most of the lower half has maximum percentage increases. A large statewide maximum of 40% occurs at Gull Lake in the southwest section of the peninsula.

An interesting result would occur if a seeding experiment were initiated in the Gull Lake to the Albion region. Both of these regions have percentage increases in the low 20's yet there exists a singular statewide maximum of 40% at Gull Lake while a minimum value of 17% occurs at Albion.

The upper half is largely in the 20's with a small minimum area around Traverse City and a small area of maximum in the extreme north near Cheboygon with a singular area at Atlanta in the north central region.

Upper Peninsula. Percentage increases are almost entirely in the 20's with two small areas of less than 20% in the extreme east, two areas in the central region, and a singular area around Iron Mountain in the south central area. A maximum region occurs in the extreme south central area.

Approximately two-thirds (66%) of the stations have percentage increases in the 20's with one-quarter of the stations greater than 30%. However, these occur chiefly in the southern half of the Lower Peninsula.

Week 24 (September 9-15)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. In this unusual week the maximums (0.7-0.8 in.) in the Lower Peninsula occur in the extreme north. A value of 0.79 in. occurs at Onaway. The northern half is composed of 0.5-0.7 in. amounts with 0.5-0.6 in. amounts prevailing in the central and east while 0.6-0.7 in. amounts occur in the central and west.

The lower half has variable precipitation amounts. Amounts of 0.4-0.6 in. occur in a diagonal area from Saginaw Bay southwestward to near Lake Michigan. Two moderately sized areas of 0.4-0.5 in. occur in the south central and southwest. A minimum region from 0.2-0.3 in. occurs in the southeast to part of the central Thumb. Generally, the remaining area is from 0.3-0.4 in.

Upper Peninsula. The amounts are larger than those of the Lower Peninsula. This time, however, a maximum region greater than 0.8 in. occurs in the extreme east and, as usual, in the central and western areas. With the exception of the extreme eastern section, the eastern half of the peninsula is generally from 0.7-0.8 in. The western area has values in the 0.7-0.9 in. range in the far west (a statewide maximum of 0.88 at Bergland Dam) with 0.6-0.7 in. totals in the rest of the western section. The central region has 0.7-0.8 in. amounts in the north (a maximum value of 0.87 in. occurs at Marquette, however), 0.6-0.7 in. in the central area, and 0.5-0.6 in. amounts in the extreme south central region. The lowest value in the Upper Peninsula is only 0.50 in. at Fayette in the extreme south central region.

Model B Percentage Increases

Lower Peninsula. A complete change occurs in the Lower Peninsula this week. Maximums occur in the south central region and in the central eastern Thumb. Minimums cover the west central region and central region from about Allegan northward to Hesperia and then eastward to around St. Charles. Another area occurs in the north central region. Tiny singular areas occur in the extreme north, west central along Lake Michigan, and in the eastern Thumb.

Upper Peninsula. The Upper Peninsula is generally in the 20's with an area of teens in the north and south central region. The state as a whole has almost four-fifths of the stations (79%) in the 20's. Maximums greater than 30% only cover 2% of the stations.

Week 25 (September 16-22)

Natural Precipitation Patterns - 50% Probability Level

Much higher amounts occur this week with 90% of the stations greater than 0.5 in.

Lower Peninsula. The upper half is dominated by 0.5-0.6 in. amounts in the south and 0.6-0.7 in. amounts further north. The northern central region has totals from 0.7-0.9

in. with a statewide maximum of 0.97 in. at Gaylord. Another small area from 0.7-0.8 in. exists in the extreme northwest. In the west central region an area of 0.4-0.5 in. occurs. The lower half is quite variable with a maximum region in the south central area. An amount of 0.88 in. occurs at Coldwater. A secondary maximum of 0.72 in. occurs in the Thumb at Caro. A minimum area of 0.4-0.5 in. occurs in the southeast lower Thumb region north of Detroit. The remainder of the lower half ranges from 0.5-0.7 in.

Upper Peninsula. Once again, the Upper Peninsula has higher precipitation amounts in the extreme east with an area of 0.8-0.9 in. occurring. Totals of 0.6-0.8 in. exist further westward. A maximum of 0.75 in. occurs at Rock in the central region. The western half is dominated by 0.5-0.6 in. amounts with an area of 0.5-0.6 in. in the region north of Iron Mountain to Lake Superior.

Model B Percentage Increases

Almost three-quarters (72%) of the stations have percentage increases between 20 and 30. Only 1% have values above 30.

Lower Peninsula. A sizeable minimum area exists in the southwest quarter. Within this area occurs a region of 20-30% increase, from around Gull Lake northward to the vicinity of Hastings. Four other singular minimums occur in the northern region near Traverse City, at Gaylord and around Onaway in the extreme north. A singular statewide maximum of 30% occurs at Lapeer in the Thumb.

Upper Peninsula. Amounts are almost entirely in the 20's with an area of teens in the extreme east and a tiny area in the south central region in the vicinity of Manistique.

Week 26 (September 23-29)

Natural Precipitation Patterns - 50% Probability Level

Lower Peninsula. This final week of the study period has a north-south pattern of precipitation unlike the previous weeks in September. The southeast has 0.2-0.3 in. amounts. The state's minimum of 0.20 in. occurs at Monroe in the Southeast. An area of 0.3-0.4 in. stretches from the south central region (including part of southwest Michigan) to the northeast region east of Mio along Lake Huron. An area of 0.4-0.5 in. stretches from the southwest area northeastward to the vicinity of Alpena. Also included is the northern and central eastern Thumb along Lake Huron. Amounts from 0.5-0.6 in. occur in the west central region and also extend in a narrow band to the northeast section of the peninsula to the east of Onaway. The northwest region has the largest amounts in the state with 0.6-0.8 in. totals. The state's maximum of 0.88 in. occurs at Charlevoix in the northwest.

Upper Peninsula. Larger amounts of precipitation occur in the east with a maximum of 0.80 in. at Detour at the extreme eastern end of the peninsula. The eastern one-third is covered by 0.7-0.8 in. precipitation amounts to the east and 0.6-0.7 in. amounts toward the west. Amounts of 0.6-0.7 in. cover the far west and the north central region in the vicinity of Grand Marais. Amounts of 0.4-0.5 in. cover the south central region and part of the Keweenaw Peninsula. The rest of the Upper Peninsula ranges generally from 0.5-0.6 in.

Model B Percentage Increases

During this week, 71% of the stations have potential increases from 20-30%.

Lower Peninsula. Maximums are more dominant in the Lower Peninsula (chiefly in the eastern half) than the previous week. Large areas of 30-40% cover part of the south central and southeast regions, the Thumb and Saginaw Bay, and the north central and eastern upper half. The state's maximum of 36% occurs at Williamston in the south central region. Smaller maximum areas are scattered throughout the Lower Peninsula in the western half.

Upper Peninsula. Amounts range generally from 20-30% with two maximum areas in the vicinity of Iron Mountain, and around Rock in the central region. A minimum area occurs in the extreme east.

September Results

Natural Precipitation Patterns - 50% Probability Level

The amount of precipitation that falls during the month of September is most evident by noting the percentage of stations above 0.5 in:

Week 23: 26% > 0.50 in.

Week 24: 66% > 0.50 in.

Week 25: 89% > 0.50 in.

Week 26: 40% > 0.50 in.

Early September continues like the last week of August in being extremely dry statewide. The precipitation increases during the month and by the third week large amounts fall. Then the amounts decrease rapidly at the end of the month.

Lower Peninsula. The pattern of precipitation in the Lower Peninsula is consistent in that extreme maximum areas are concentrated in the northwest section of the peninsula. For example, during week 23 the largest amounts in the Lower Peninsula fall from the vicinity of Kalkaska to the northern tip with amounts from 0.5-0.6 in. During week 24 the greatest amounts cover the extreme northern region with many amounts in excess of 0.7 in. During week 25 there are two exceptions. A maximum area with a peak of 0.88 in. occurs in the extreme south central area and a smaller maximum of 0.75 in. occurs in the central region. However, the largest amounts still fall in the northwest with some areas being in excess of 0.90 in. (A maximum of 0.97 in. occurs at Gaylord).

By week 26, precipitation is less but the maximum still occurs in the northwest with values in excess of 0.80 in. (a maximum of 0.88 in. occurs at East Jordan).

Upper Peninsula. Generally, the amounts of precipi- during the month are larger than the Lower Peninsula. What is noticed this month is that maximum quantities of precipitation fall in the eastern region, an area previously dominated by minimums. This is most evident during the last two weeks where amounts near 0.8 in. occur. What is also interesting during the latter half of September is the lack of precipitation maximums in the western section. This is quite a contrast to the existing pattern in previous months.

Model B Percentage Increases

Lower Peninsula. Week 23 is dominated by maximum areas greater than 30% in the lower half of the Lower Peninsula. A singular area of 40% occurs around Gull Lake. The upper half is generally from 20-30% with the exception of some small maximum areas in the north.

During week 24, the maximum area is replaced by increases of 20-30% with a large minimum region in the central area from Lake Michigan to the center of the state. Only two small maximums are left in the Lower Peninsula, in the south central region, and in the Thumb.

Week 25 shows the change to minimum areas to an even greater degree. Minimums cover the entire southwest quarter of the Lower Peninsula with the exception of a region in the center of this minimum area. A tiny singular maximum is located at Lapeer.

The final week has abrupt changes. Large maximum areas occur in the northwest, Thumb, south central, and part of the southeast regions. Small minimum areas are confined to the western half of the state.

A noticeable pattern this month is that no major region of minima exists in the eastern region of the Lower Peninsula.

Upper Peninsula. Amounts range mainly in the 20's, with only small areas of maximum and minimum in the central and far eastern sections. The far eastern region is consistently less than 20%.

Based on percentage increases alone, seeding in the Lower Peninsula would be more profitable during the first and last weeks of September. In the Upper Peninsula, all weeks would be average with lower percentage increases in the far eastern region.

Model B Additional Precipitation

Week 23. The only major maximum region (0.12-0.16 in.) in the Lower Peninsula occurs in the far north with smaller scattered regions elsewhere. Minimums of 0.04-0.08 in., however, cover a good portion of the lower half with a statewide minimum of 0.03 in. in the vicinity of Allegan in the southwest.

The Upper Peninsula has increases from 0.12-0.16 in. (with a statewide maximum of 0.17 in. in the vicinity of Ishpeming) except in the extreme northwest, south central and extreme eastern regions.

Approximately 30% of the stations (principally in the Lower Peninsula) have increased less than 0.08 in.

Week 24. The Lower Peninsula is virtually cut in half with maximum areas of 0.12-0.16 in. in the northern half. Large values in excess of 0.16 in. occur in the extreme north and a region of 0.08-0.12 in. extends from Saginaw Bay westward. Another area above 0.16 in. occurs in the vicinity of Cadillac. The lower half has minimum regions of 0.04-0.08 in. in much of the southeast and lower Thumb and in an area in the southwest. The statewide minimum of 0.06 in. occurs in many localities in the southeast. Other scattered areas of maximum and minimum cover the peninsula.

The Upper Peninsula has very large increases with the smallest increase being only 0.12 in. in the vicinity of Iron Mountain. Areas of 0.16 in. occur in the central and western regions. The statewide maximum of 0.20 in. occurs in the vicinity of Munising in the north central region.

Approximately 61% of the stations have values in excess of 0.12 in.

Week 25. Most of the upper two-thirds of the Lower Peninsula has values in excess of 0.12 in. with the exception of a small area in the northeast and west central region. Areas in excess of 0.16 in. cover the extreme northwest and an area in the north central region. The statewide maximum of 0.19 in. occurs in the vicinity of Pellston and Charlevoix. Another maximum area (0.12-0.16 in.) occurs in the extreme southeast. The statewide minimum of only 0.09 in. occurs in the vicinity of Three Rivers.

The Upper Peninsula has all values in excess of 0.12 in. with areas of 0.16-0.20 in. in the far west and east and in a small area in the central region.

Approximately 78% of the stations have values this week in excess of 0.12 in.

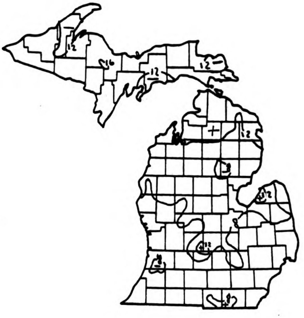
Week 26. Maximums of 0.12-0.16 in. cover at least the northwest one-third of the Lower Peninsula with values of 0.16-0.20 in. in the far north. The statewide maximum of 0.19 in. occurs in the vicinity of East Jordan in the northwest. Another area of maximums occur in the northern Thumb. Minimums of 0.04-0.08 in. generally cover most of the southeast and part of the lower Thumb.

Approximately 53% of the stations have increases in excess of 0.12 in., principally in the northern lower Peninsula and the Upper Peninsula.

Week 23

A

B



C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 25. Precipitation Maps for Week 23 (September 2-September 8)

Week 24

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 26. Precipitation Maps for Week 24 (September 9-September 15)

Week 25

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 27. Precipitation Maps for Week 25 (September 16-September 22)

Week 26

A

B

C

A. Precipitation at 50% Prob. Level (X 0.1)

B. Model B Percentage Increase

C. Model B Additional Precipitation (X 0.01)

Figure 28. Precipitation Maps for Week 26 (September 23-September 29)

SUMMARY

Actual Precipitation

The percent of Michigan Stations having weekly precipitation greater than 0.5 in. at the 50% probability level are listed in Table 2. During the spring Lake Michigan has little influence on precipitation patterns. The largest amounts are generally found in southern lower Michigan. In the upper peninsula the largest amounts are found in the west.

The summer pattern shows influence of Lake Michigan in decreasing rainfall. The western half of the upper peninsula has considerably more rainfall than the lower peninsula. Higher rainfall amounts occur in the extreme southcentral and southwest regions and the northcentral region. Higher terrain in these areas in part accounts for the additional precipitation.

During the fall Lake Michigan aids in producing rainfall especially in the northwest lower peninsula and the eastern upper peninsula.

The largest amounts of rain during the growing season generally occur in the southcentral, southwest, and northcentral regions. The largest areas, however, occur in the upper peninsula with rainfall in excess of ten inches. Minimum rainfall occurs in the Saginaw Bay region, the southeast, west central regions and the extreme northern lower peninsula. In the upper peninsula the least rainfall occurs in the extreme east.

Percentage Increase

The percentage of stations with greater than a 30% increase of precipitation when using Changnon's Model B are listed by week in Table 3. This study shows the largest percentage increase from seeding would occur during the second week of April and during late April and early May.

For the growing season, values ranged from less than 10 to greater than 14% increase. The largest percentage increases are found in the northeast and west central lower peninsula along with the extreme eastern upper peninsula.

Additional Precipitation

The largest additional rain occurs in April during weeks one, three and four as well as during week 25 in mid-September. Both late May and mid June have moderate increases. During the summer, only late July and late August provide moderate additional rain.

During the growing season the maximum areas of additional rain are confined to the extreme southcentral region and the northeast lower peninsula. A large minimum area stretches along the southern Lake Michigan shoreline. The upper peninsula by far has the highest increases statewide. In the western half amounts are in excess of 1.5 in.

Statewide the range is from less than .8 to more than 1.5 in.

TABLE 2

PERCENT OF MICHIGAN STATIONS HAVING WEEKLY PRECIPITATION GREATER THAN 0.5 INCH AT THE 50% PROBABILITY LEVEL

Week	Inclusive Dates	Percentage >0.50 in.
1	April 1 - 7	35
2	April 8 - 14	0
3	April 15 - 21	52
4	April 22 - 28	86
5	April 29 - May 5	8
6	May 6 - 12	42
7	May 13 - 19	16
8	May 20 - 26	33
9	May 27 - June 2	32
10	June 3 - 9	12
11	June 10 - 16	62
12	June 17 - 23	58
13	June 24 - 30	53
14	July 1 - 7	25
15	July 8 - 14	33
16	July 15 - 21	53
17	July 22 - 28	40
18	July 29 - Aug. 4	43
19	Aug. 5 - 11	29
20	Aug. 12 - 18	1
21	Aug. 19 - 25	20
22	Aug. 26 - Sept. 1	59
23	Sept. 2 - 8	26
24	Sept. 9 - 15	66
25	Sept. 16 - 22	90
26	Sept. 23 - 29	40

TABLE 3

PERCENT OF MICHIGAN STATIONS HAVING GREATER THAN 30% INCREASE OF RAINFALL AT THE 50% PROBABILITY LEVEL (Model B)

Week	Inclusive Dates	Percentage >30%
1	April 1 - 7	37
2	April 8 - 14	66
3	April 15 - 21	18
4	April 22 - 28	1
5	April 29 - May 5	40
6	May 6 - 12	6
7	May 13 - 19	29
8	May 20 - 26	24
9	May 27 - June 2	10
10	June 3 - 9	25
11	June 10 - 16	4
12	June 17 - 23	2
13	June 24 - 30	5
14	July 1 - 7	19
15	July 8 - 14	6
16	July 15 - 21	2
17	July 22 - 28	6
18	July 29 - Aug. 4	2
19	Aug. 5 - 11	5
20	Aug. 12 -18	26
21	Aug. 19 - 25	13
22	Aug. 26 - Sept. 1	4
23	Sept. 2 - 8	26
24	Sept. 9 - 15	2
25	Sept. 16 - 22	1
26	Sept. 23 - 29	22

TABLE 4

PERCENT OF MICHIGAN STATIONS HAVING
ADDITIONAL RAIN GREATER THAN 0.12 IN.
(MODEL B)

Week	Inclusive Dates	Percentage >0.12 in.
1	April 1 - 7	65
2	April 8 - 14	4
3	April 15 - 21	70
4	April 22 - 28	83
5	April 29 - May 5	43
6	May 6 - 12	27
7	May 13 - 19	32
8	May 20 - 26	63
9	May 27 - June 2	50
10	June 3 - 9	27
11	June 10 - 16	57
12	June 17 - 23	57
13	June 24 - 30	44
14	July 1 - 7	19
15	July 8 - 14	17
16	July 15 - 21	26
17	July 22 - 28	28
18	July 29 - Aug. 4	43
19	Aug. 5 - 11	28
20	Aug. 12 - 18	5
21	Aug. 19 - 25	17
22	Aug. 26 - Sept. 1	47
23	Sept. 2 - 8	36
24	Sept. 9 - 15	61
25	Sept. 16 - 22	78
26	Sept. 23 - 29	53

CONCLUSIONS

1. This study demonstrates the advantage of developing weekly climatologies vs. only monthly climatologies.

A weekly rainfall climatology reveals precipitation patterns better than do monthly climatologies. Many climatological studies have been done using only monthly rainfall amounts. As shown in this study, however, significant weekly variability is masked by using only monthly precipitation. Therefore, a weekly precipitation climatology is necessary to assess true precipitation patterns within an area.

2. Computer simulations can be used to assess the potential effect of cloud seeding.

Climatologies using percentage increase of precipitation and actual increase of precipitation are both useful for assessing the potential impact of cloud seeding. In this study most weeks which had the greatest increase of actual precipitation had the least percentage increase of precipitation. Weeks with small increase of actual precipitation had the largest percentage increase of percipitation.

When attempting to model crop yields over an entire growing season, analyses using the actual precipitation increase would be most beneficial. A large actual increase of precipitation would be important in increasing crop yield. An analysis for drought relief, however, may require analyzing the percentage increase of precipitation. A large percentage increase of precipitation may signify reduction of drought related problems.

3. Studies such as this can be used in weather modification planning and verification.

Cloud seeding should be conducted over a period of years in order to assess its effectiveness in an area. The computer models used in this study are based upon actual precipitation recorded in Michigan from 1949-1971. Due to the natural variation of precipitation in any year, cloud seeding results for a given year are very hard to quantify. Therefore, cloud seeding operations must continue over a period of years in order to develop a significant data base from which cloud seeding effectiveness can be determined.

The study reported here can be used to select target and control areas within Michigan. Locations with similar model results will most likely be representative of normal area rainfall in the future. Wise selection of target/control areas can go a long way toward answering questions about cloud seeding effectiveness.

RECOMMENDATIONS

1. Use output of the cloud seeding model to estimate crop yield changes with increased rainfall.

This model seems to be a realistic estimate of increased rainfall. By applying precipitation amounts output by this model to crop growth and yield models, estimates of increased yield due to potential cloud seeding precipitation can be determined.

2. Use output of the cloud seeding model for estimating soil moisture changes possible with cloud seeding.

The ultimate objective for increasing precipitation is to supply growing crops with water. Since soil stores moisture for future use, any alteration in soil moisture status due to precipitation increases should be determined. This is important in order to properly assess feasability for economic return from cloud seeding.

3. Apply the cloud seeding model to other regions in order to assess cloud seeding potential.

The cloud seeding model used in this study can be used in areas of the midwest and perhaps the world to determine both increase of crop yield and soil moisture due to precipitation changes. It is important to remember that the model was originally proposed for relatively flat terrain with predominately cumulus type rainfall. These conditions are prevalent during the warmer seasons throughout the central part of the United States and in other areas of the world. Applying this model and techniques used in this study will aid in feasability studies for precipitation changes due to cloud seeding.

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