"REVIEWED"

ASSESSMENT OF WEATHER MODIFICATION POTENTIAL FOR ALLEVIATING AGRICULTURAL DROUGHTS IN THE MIDWEST

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INTRODUCTION

During 1976-1977, hydroclimatological research was undertaken to help assess the potential utility of weather modification in stimulating crop production during droughts of various intensity in the Midwest. A secondary objective was to develop techniques for applying precipitation climatology in assessing the feasibility and potential benefits of cloud seeding during growing season droughts. This research was limited to Illinois which is typical of much of the Midwest in climate, soils and crop production. The results should provide useful input into future decision-making pertaining to the use of weather modification for alleviating agricultural droughts. Findings should be useful in establishing the limitations of weather modification in agricultural applications, and should assist in determing the scope and direction of future research in weather modification.

DATA USED

Precipitation data for the period 1900-1974 were used to determine storm, monthly and seasonal rainfall amounts. In those analyses requiring hourly rainfall, analyses had to be limited to the period since 1940 when a major increase in the number of recording raingages was initiated. Prior to that time, only a few tipping bucket recording gages, usually located at first-order stations, were available. Certain mesoscale studies were made through use of data from the 1971-1975 METROMEX Project (Changnon, et al., 1971), which involved extensive research on inadvertent weather modification and utilized a network of 225 recording raingages in 5200 km^2 (2000 mi^2) centered on St. Louis. Limited studies of cloud climatology and thermodynamic conditions in wet and dry periods were made also, but are not included in this paper which concentrates on precipitation relations. Normality of rainfall, used frequently in the text, was based on 1906-1955 (50 yr.) which spanned most of the drought sampling period, and included two major droughts and two outstanding wet periods.

ANALYTICAL APPROACH

Two time periods were used in the study. The first is the 2-month period of July and August which earlier studies had shown is the most critical period in the relationship between crop production and precipitation for two major midwestern crops, corn and soybeans (Changnon and Neill, 1967; Huff and Changnon, 1972). The second analytical period spans the growing season from May through September which includes much of the planting, all of the plant growth, and major portions of the harvesting in the Midwest for most crops.

Investigation was made of July-August droughts in which portions of Illinois experienced 2-month rainfalls that were 50% or less of the normal precipitation. This provided a sample of 35 droughts in the 75 years of records (1900-1974) used in the agro-climatic research. For the growing season, analyses were made of droughts in which the 5-month rainfall was less than 70% of normal. By this definition, a sample of 14 outstanding droughts was obtained for detailed meteorological analyses. The 35 July-August droughts provide a sample of events that occur approximately once in two years, on the average. The 14 May-September droughts sample 5-year average occurrences. A larger sample of July-August dry periods was selected for study because of the more critical need for plentiful rainfall in this period to insure good crop yields.

The drought samples incorporated a wide variety of conditions and included (1) widespread severe droughts often involving several states such as occurred in the early 1950's (2) moderate droughts which usually persist for one or two growing seasons over portions of one or more states, and (3) spot droughts which frequently occur over isolated areas of several contiguous counties or a region of the states, and which are surrounded by areas of near-normal or above-normal rainfall.

Analyses were concentrated on assessment of the distribution characteristics of natural rainfall in droughts. Previous studies in Illinois (Huff, 1969; Huff and Semonin, 1975; Changnon et al., 1977) have indicated that significant seeding-induced increases in summer rainfall must be achieved through enhancement of ongoing convective rain systems, and most of this would have to be produced in conjunction with organized storm systems. Previous cloud climatological studies also indicated too few low clouds (rain producers) present during dry periods to generate significant rainfall over the relatively large areas usually affected by drought conditions (Semonin, 1960; Huff and Changnon, 1963). Results of the present research are briefly summarized in the following pages. In this paper, analytical methods are described briefly and the most pertinent findings summarized. Major emphasis is placed upon the very critical July-August droughts. For those interested, all phases of the research are described in detail in an NSF research report (Huff and Vogel, 1977). Meteorological stations and state climatic sections used in the studies are shown in Fig. 1.

AREAL EXTENT AND FREQUENCY OF RAINFALL IN JULY-AUGUST DROUGHTS

Droughts were grouped by areal extent as a measure of severity. Areas ranged from less than 1000 km^2 to nearly 100,000 km^2. Table 1 shows the spatial distribution taken from a frequency distribution curve derived from the 35 droughts. This table indicates that the 2-month droughts do not usually extend over a large portion of the state. Only once in 6 years, on the average, does a drought occur over 10% or more of Illinois, and more than 50% of the state is involved only once in 50 years. The relatively small size of these droughts in the two most critical months of the growing season should be favorable from the standpoint of rain modification potential. That is, productive storm systems are crossing the state, but a relatively small percentage of the area is consistently underfed by these systems.

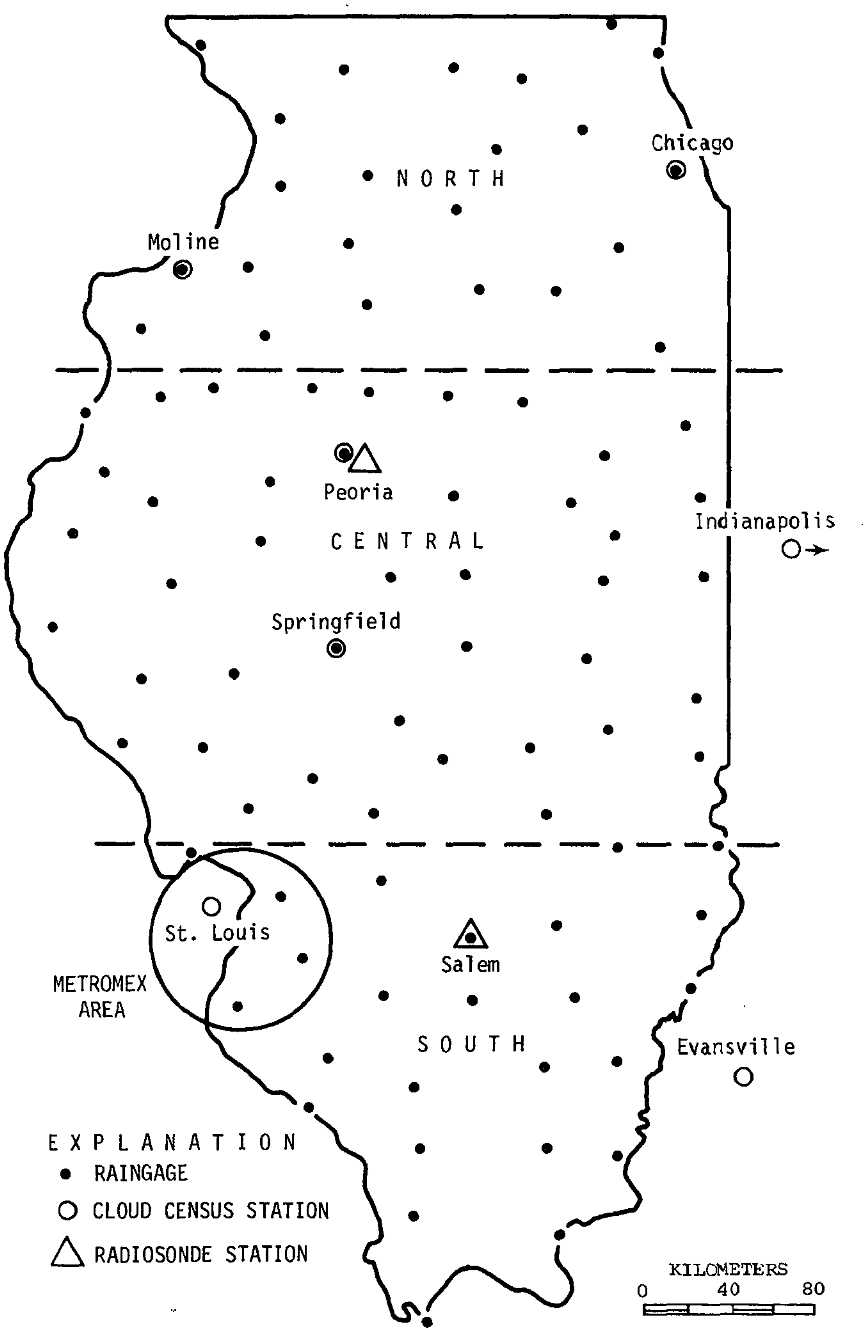

FIGURE 1. Meteorological Stations and State Divisions

Table 1. Frequency Distribution of Areas in July-August Droughts of Moderate to Severe Intensity in Illinois

Frequency (years)	Area Equalled or Exceeded km^2	mi^2	Percent of State
2	1,550	600	1
3	4,660	1,800	3
5	11,650	4,500	8
10	25,900	10,000	18
25	51,800	20,000	35
50	77,700	30,000	53

Areas immediately surrounding droughts were usually below-normal also, but the precipitation deficiency was not nearly as large. These areas tend to average over twice the rainfall in the adjacent drought area, so that the possibility of seeding-induced enhancement is much better. Seeding of storms in these periphery areas would appear to offer an opportunity for extending the enhancement at least into the fringes of the major drought area by inducing larger and longer-duration convective entities.

Analyses were made of the frequency of months with 80, 100 and 120 percent of normal rainfall within the July-August droughts as another guide in assessing weather modification potential. Indications were that only small portions experience near normal rainfall in either of the two consecutive months. Only 11 of the 70 months in the 35 July-August droughts had any area with rainfall exceeding 80% of normal. Among these 11 months, the median was 9% of the drought area with a range from 4 to 37%. Thus, it tends to be very dry within the droughts throughout the 2-month period. This is not a particularly favorable situation from the standpoint of seeding enhancement of ongoing storms, but does not preclude seeding success in drought situations.

Area-depth curves were derived for each drought to provide more detailed quantitative information on the spatial distribution characteristics than is provided by average rainfall statistics for these extreme events. As used here, these curves provide a measure of the minimum rainfall, rainfall gradient, and rainfall amounts enveloped within partial areas of droughts of various extent (Huff, 1968). Quantitative estimates of the additional production of rainfall from weather modification operations should be more reliable if the spatial distribution characteristics of rainfall in droughts of various severity are better known. Thus, the area-depth relationships provide basic information needed to help evaluate potential benefits of weather modification in agriculture in Illinois and areas of similar precipitation climate.

Area-depth curves were drawn for each July-August drought. These individual drought relations were then combined to derive the family of curves in Fig. 2 (see Huff and Vogel, 1977 for details of the derivation). Figure 2 shows the average distribution of rainfall, expressed as percent of normal for July-August, within droughts extending over areas of various size. For example, in a drought encompassing 25,000 km^2 (10-year event), approximately 1000 km^2 of the 25,000 km^2 would have rainfall less than 22% of normal. This increases to 25, 31 and 36% of normal, respectively, for the dryest 2000, 5000, and 10,000 km^2 with the 25,000-km^2 drought.

All analyses performed on the July-August droughts was repeated for the May-September dry periods. In general, results showed the 5-month droughts were less severe than the 2-month mid-summer droughts, and, consequently, that seeding opportunities occur with a greater average frequency than during July-August (Huff and Vogel), 1977).

INTENSITY OF DAILY RAINFALL

Analyses were made to determine the frequency and areal extent of daily rainfalls equalling or exceeding 0.25 mm (0.01 inch), 12.7 mm

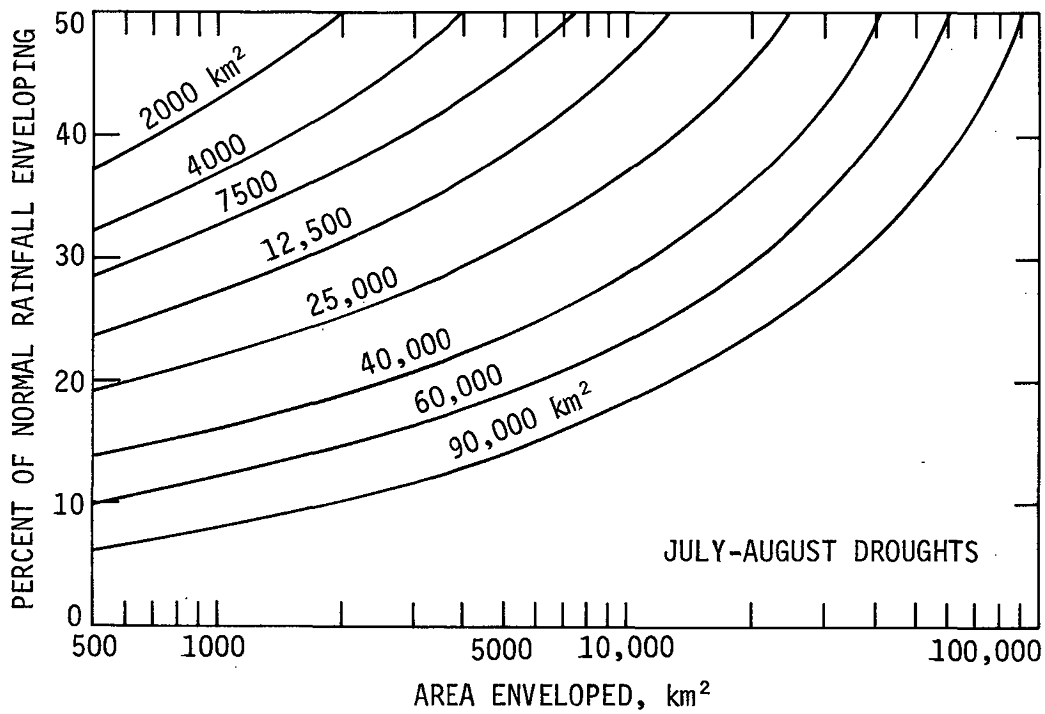

FIGURE 2. Typical Spatial Distribution of Rainfall in July-August Droughts

(0.50 inch) and 25.4 mm (1.00 inch) in July-August droughts. The purpose was to obtain further information on the characteristics of droughts and the causes of their precipitation deficiencies. Results indicated that there are nearly always two days or more per month with measurable rainfall (0.25 mm) at all points within the drought areas of July-August, but this is only a small percentage of the normal frequency of 9 days. Approximately 50% of the drought areas were found to have 6 or more days with measurable rainfall, 20% experienced 8 days, and only 4% had 10 days. These statistics are indicative of the number of days with potential for seeding enhancement of natural rainfall. The opportunities are not too infrequent, but the natural rain area usually extends over only a small portion of the drought region.

Analyses indicated only 18% to 20% of the July-August drought areas have two or more days per month with rainfall of 12.7 mm or more, whereas normally the entire area should experience this number of moderate rain days. Furthermore, only 14% of the drought areas, on the average, were found to have one day per month with rainfall exceeding 25 mm, whereas in a perfectly normal year this intensity would be experienced once at all locations.

In view of the small percentage of the July-August drought areas experiencing moderate to heavy rainfalls, natural rainfall would have to be increased by large percentages when seeding conditions are favorable to produce useful increases over more than a small percentage of the stricken area.

The areal extent of light, moderate, and heavy rainfall days in the area immediately surrounding the drought regions showed deficiencies in all categories but of a much lesser degree. Thus, on the average, there was 35% of the area with 8 days of measurable rainfall compared with 20% inside the drought area. Similarly, 59% of the surrounding area had 2 days per month with rainfall of 12.7 mm or more compared with 18% in the drought region, and one day with 55% coverage compared with only 13% inside the drought area. Thus, seeding opportunities are much more frequent in all categories in the surrounding areas, and, if seeding can induce longer lasting and larger convective entities the prospects for alleviating the water deficiencies on the outer portions of drought areas would appear favorable.

Similar conclusions were reached from analyses of daily rainfalls in and surrounding the May-September droughts. However, seeding opportunities, as indicated by the areal extent of light, moderate, and heavy daily rainfalls, are considerably greater than in the July-August droughts, which is in agreement with findings from various types of rainfall analyses performed in the research.

DIURNAL DISTRIBUTION

Diurnal distribution should be considered in planning the time and duration of weather modification activities to maximize contributions from seeding effects. No major differences were found between the diurnal distributions during drought situations and average weather conditions. In the northern two-thirds of Illinois, the maximum amount of rainfall tends to occur in the early morning (0000-0600), whereas in the southern part there is a distinct afternoon maximum.

All diurnal analyses showed that substantial percentages of the total rainfall in the growing season occur throughout the day and night. This stresses the need to carry out weather modification operations on a 24-hour basis to take maximum advantage of seeding opportunities during droughts. At least 50% of the Illinois rainfall occurs from 1800 to 0600 CST, and approximately 25% from midnight to 0600. Based upon frequency of maximum rainfall amounts in Illinois droughts, the greatest number of seeding opportunities are likely to occur from 1500 to 2100.

DISTRIBUTION OF STORM RAINFALL IN DROUGHTS

Mean rainfall computations were made in each of 492 storms in the 35 July-August droughts studied in this research. From these computations, frequency distributions of mean rainfall were derived for droughts of various areal extent. These distributions were derived to provide a measure of the frequency of storm mean rainfalls of various intensities in droughts of various severity, as measured by area encompassed by the drought. Results are summarized in Table 2 and show that heavier storms tend to occur more frequently in small-area droughts. For example, storm mean rainfall equalled or exceeded 11 mm in 20% of the storms sampled on drought areas of less than 5000 km^2, whereas the equivalent mean rainfall was 6 mm in droughts extending over areas of 50,000 km^2. However, the most important contribution from this analysis is the quantitative estimates of storm mean rainfall distributions in moderate to severe mid-summer droughts in Illinois and Midwest. This information should be extremely useful in evaluating seeding potential in such situations, and, consequently, in the planning of weather modification activities to alleviate agricultural water shortages.

The characteristics of drought-associated rainstorms were defined further through computation of area-depth relations for all 492 storms. Rainfall was accumulated from high to low amounts. These computations provided pertinent information on the spatial distribution of rainfall within storms. Droughts were divided into six groups, based upon areal extent. For each drought group, median area-depth relations (Fig. 3) were developed to show the percentage of the drought area with storm rainfall amounts equalling or exceeding any chosen value. For example, in small droughts enveloping areas of 1000-4000 km^2, the median storm was found to have rainfall equalling or exceeding 10 mm over 20% of the area, 3 mm over 50% of the area, and 0.7 mm over 80% of the area. In droughts enveloping 50,000 km^2 or more, similar values were 5 mm, 0.3 mm and none. In addition to the group average relations, the median area-depth envelope relationship in each specific drought was computed (Huff and Vogel, 1977).

As another guide in the evaluation of weather modification potential in moderate to severe droughts, the area-depth relations for the 492 storms and the frequency distributions for storm mean rainfalls were used to develop a nomogram technique for computing the average spatial distribution of rainfall in storms of any given intensity (areal mean rainfall) over a wide range of areas (3,000-75,000 km^2) in July-August droughts. This technique provides the user with a quantitative estimate of the <u>average</u> spatial distribution characteristics of storm rainfall in the area of interest under

Table 2. Distribution of Storm Mean Rainfall in July-August Droughts of Various Areal Extent

Drought Area (km^2)	Storm Mean Rainfall (mm) Equalled or Exceeded for Given Percent of Storms										
	5	10	20	30	40	50	60	70	80	90	95
>50,000	10.4	7.5	6.0	5.0	4.5	2.5	2.3	1.3	0.8	0.4	0.2
10,000-50,000	14.5	10.0	7.5	5.5	4.7	2.8	2.4	1.4	0.8	0.4	0.2
5,000-10,000	16.0	13.5	9.5	6.7	5.0	3.0	2.5	1.5	0.8	0.4	0.2
< 5,000	18.5	15.5	11.0	7.0	5.0	3.0	2.5	1.5	0.8	0.4	0.2

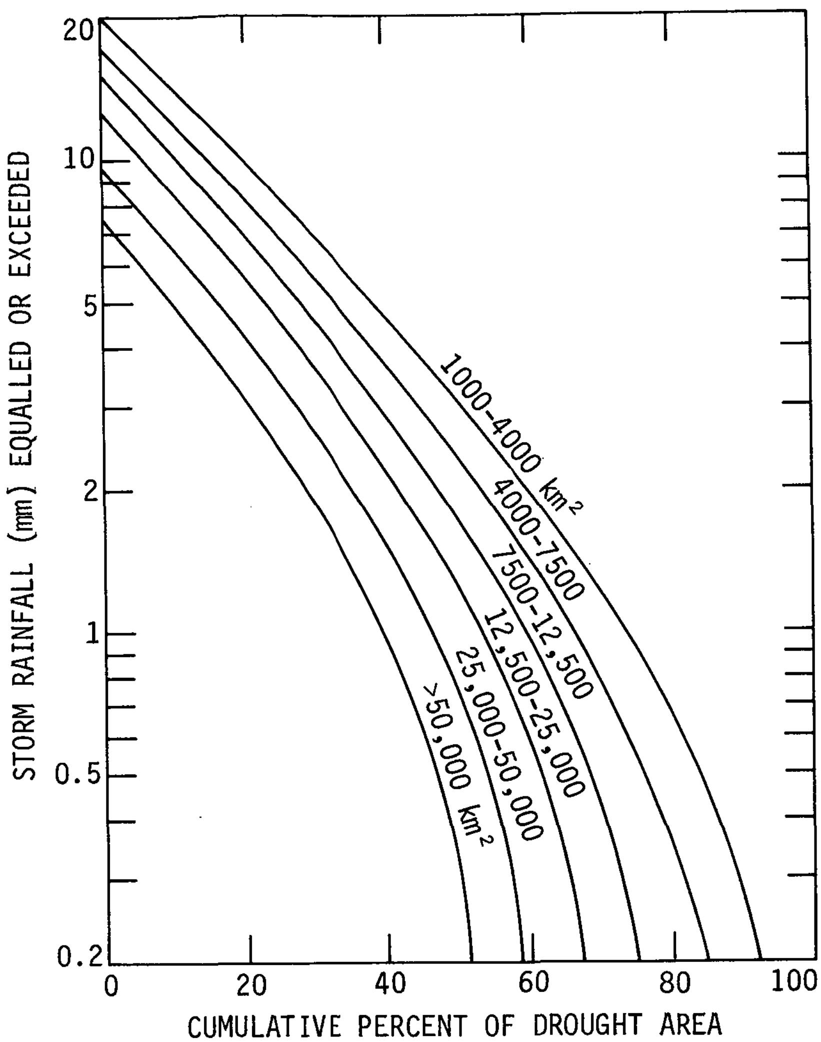

FIGURE 3. Median Area-Depth Envelope Curves of Storm Rainfall in July-August Droughts of Various Sizes

given conditions of drought areal extent and storm mean rainfall. This capability should be very useful both in evaluating the potential benefits of weather modification and in planning cloud seeding operations.

The nomogram technique was developed in non-dimensional terms, and is considered applicable in the Midwest, in general, and other areas of similar precipitation climate. The specific inputs required are the storm mean rainfall and size of area. These then determine the non-dimensional area-depth relation to be used for estimating the spatial distribution of the storm rainfall. The July-August nomogram is shown in Fig. 4. Its use in conjunction with Table 2 is illustrated in Fig. 5.

RELATIONS BETWEEN SYNOPTIC WEATHER AND RAINFALL

The 492 storms associated with the 35 July-August droughts were classified into several basic synoptic types, depending upon whether the rainfall was associated with fronts (warm, cold, stationary, occluded), squall lines, low center passages, or non-frontal air mass activity. Analyses showed that cold fronts and pre-frontal squall lines were the major contributors of the rainfall recorded in the mid-summer droughts. These storms produced 61% of the total drought rainfall, and substantial alleviation of agricultural water shortages will, therefore, be strongly dependent upon successful enhancement of the natural rainfall associated with these systems.

The basic synoptic types used in the study are shown in Table 3 where the normal percentage distribution of each type is shown for Illinois during July-August. For some phases of the analyses, cold frontal storms were subdivided into prefrontal squall lines, fronts with waves, and frontal passages.

The frequency distribution of synoptic types was investigated for droughts stratified by areal extent to determine whether the cold front dominance persisted in all sizes of droughts. Results verified the importance of the cold frontal storms. No pronounced trend was found for any of the synoptic weather frequencies to increase or decrease their rainfall contribution as droughts became larger or smaller in their area of influence (Huff and Vogel, 1977).

As shown in Tables 3 and 4, the relative importance of cold fronts is greater in droughts than in average weather conditions. Thus, their average drought frequency was 61% of all storms (Table 4), whereas their normal frequency in Illinois is 46% (Table 3). Conversely, the frequency of air mass storms showed a pronounced decrease from 30% under normal conditions to only 11% in July-August droughts. This provides further evidence that cold fronts (and their pre-frontal squall systems) offer the greatest opportunity for rainfall enhancement in droughts. At the same time, indications are that seeding of unorganized air mass activity is likely to produce little enhancement over the drought areas as a whole, although it could help in isolated spots within the general drought area.

The importance of rainfall associated with cold frontal systems was brought out further in analysis of total rainfall contributions by synoptic

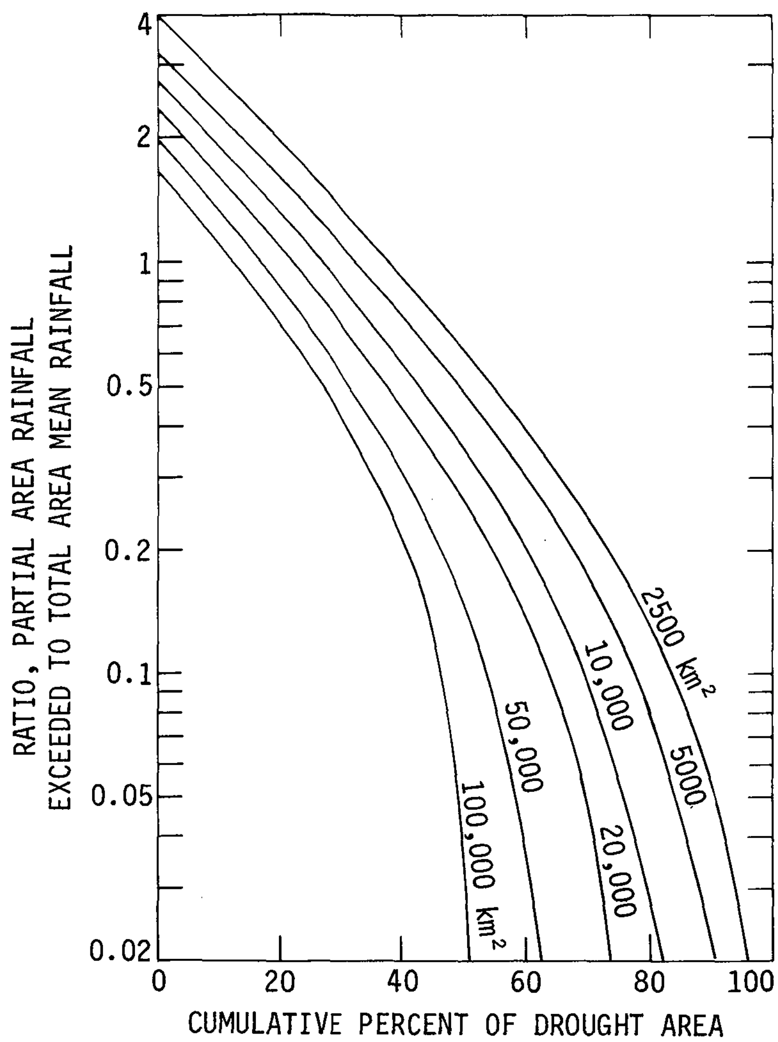

FIGURE 4. Nomogram for Estimating Spatial Distribution of Storm Rainfall in July-August Droughts of Various Areal Extent.

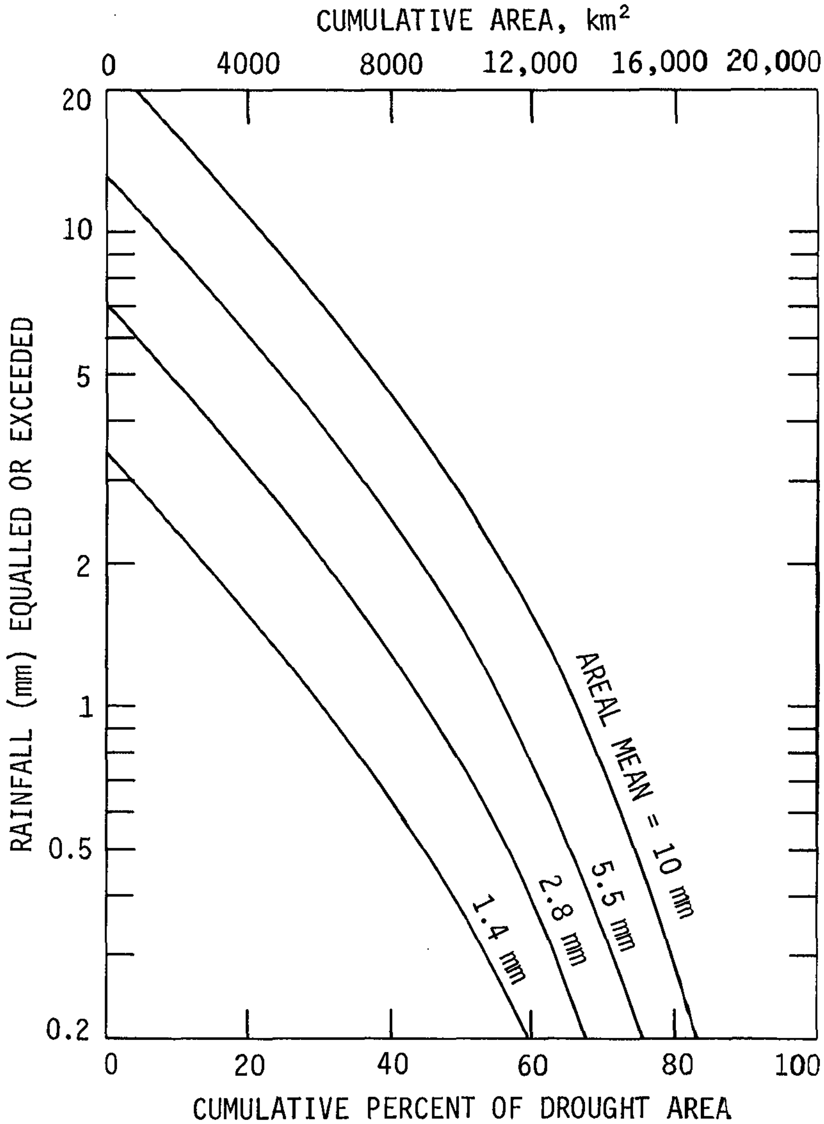

FIGURE 5. Example of Storm Area-Depth Relations Computed from Table 2 and Nomogram of Figure 4 for Drought Area of 20,000 km^2 and Selected Areal Mean Rainfalls.

Table 3. Normal Percentage Distribution of July-August Rainfall in Illinois by Synoptic Type

Synoptic Type	Percent of Storm Days	Percent of Total Rainfall
Cold Front	46	39
Warm Front	8	14
Stationary Front	13	21
Occluded Front	1	2
Low Centers	2	7
Air Mass Storms (Non-Frontal)	30	17

Table 4. General Relationships Between Storm Rainfall and Synoptic Weather Conditions in 35 July-August Droughts

Synoptic Type	Number of Storms	Percent of all Storms	Total Rainfall (cm)	Total Rainfall (in)	Percent of Total Rainfall
Cold Front	304	61	147.0	57.88	65
Warm Front	14	3	5.2	2.04	2
Static Front	80	16	37.9	14.91	17
Occluded Front	3	1	1.5	0.61	1
Lows	38	8	20.6	8.12	9
Air Mass	53	11	13.5	5.30	6

types. Cold fronts normally contribute approximately 39% of the total rainfall during July-August in Illinois (Table 3), but contributed 65% of the total in the 35 droughts studied (Table 4). Air mass contribution decreased from an average of 17% normally to only 6% in droughts.

The frequency distribution of areal mean rainfall by synoptic type was determined to provide additional background information for use in assessment of weather modification potential. Results are summarized in Table 5 and show that the heaviest rainfalls tend to occur with cold front waves and with prefrontal squall lines. Stationary fronts, although relatively infrequent (16% of total occurrences), tend to produce relatively heavy areal mean rainfalls in mid-summer droughts. As expected, air mass means tend to be light with their storm mean rainfalls being only about 25% of the average rainfall generated by cold front waves and squall lines.

The same computations were performed for May-September as described above for the July-August droughts, and results were similar. Cold fronts were the major rain contributor in the May-September droughts, and produced total rainfall in the 14 droughts that averaged near normal for this storm type. Conversely, non-frontal air mass storms produced only 5% of the drought rainfall compared with 17% normally. Cold fronts were associated with 63% of the total drought rainfall.

The relationship between drought rainfall and synoptic storm types provides another guide for use in assessing weather modification potential and in planning seeding operations. From the standpoint of weather modification, it is apparent that the greatest contributions to alleviating agricultural water shortages would come from successful treatment of cold frontal storms. Conversely, enhancement of non-frontal storms (air mass) would normally contribute little additional precipitation during drought periods.

RAINCELL INITIATIONS IN WET AND DRY PERIODS

Valuable information pertaining to rainfall characteristics during warm season droughts was obtained from analyses of raincell data obtained from the METROMEX Network of 225 recording raingages for the summers of 1971-1975 (Fig. 6). These data were analyzed to determine the characteristics of raincell initiations and mergers in wet, dry and moderate precipitation conditions. Major emphasis was placed upon dry period conditions and observed differences in the distribution characteristics between wet and dry months. Of particular interest was whether inadvertent weather modification occurred during below-normal rainfall periods and, if so, how the magnitude of this effect compared with similar effects in normal to above-normal rainfall periods.

Results of the analysis of raincell initiations (Huff and Vogel, 1977) indicate that initiations are most concentrated in and downwind of the source of inadvertent weather modification, that is, the urban-industrial areas of St. Louis and Wood River in both relatively wet and dry months. Topographic influences were also indicated with an above normal frequency of initiations along the river valleys and in the Ozark foothills. Although urban and topographic effects are present in months of below normal, near normal, and above normal rainfall, the effect relative to the rest of the network appears to be slightly greater in relatively dry months. This provides positive evidence that convective activity can be stimulated to some extent by weather modification in dry periods. Success in alleviating agricultural water shortages would depend upon whether the increased number of raincells result in beneficial increases in surface rainfall. This cannot be determined from the raincell analyses performed here.

Table 5. Frequency Distribution of Areal Mean Rainfall Associated with Various Synoptic Storm Types in July-August Droughts

	Areal Mean Rainfall (mm) Equalled or Exceeded for Given Percent of Storms										
Storm Type	5	10	20	30	40	50	60	70	80	90	N
Cold Fronts	13.2	9.9	7.4	5.6	3.8	2.8	2.0	1.3	0.8	0.3	201
Cold Front Waves	16.8	11.7	8.9	7.9	6.4	4.8	3.6	2.3	1.3	0.8	42
Cold Front Squall Lines	19.3	16.3	10.2	7.6	6.6	4.6	3.6	2.5	1.3	0.8	61
Static Fronts	16.3	11.2	7.6	5.8	4.1	3.0	1.8	1.3	0.8	0.5	80
Warm + Occluded Fronts	15.2	12.2	7.4	5.1	3.0	2.3	1.8	1.5	1.0	0.3	17
Lows	18.1	14.5	11.7	6.4	4.6	2.0	1.8	1.3	1.0	0.8	38
Air Mass Storms	11.4	7.4	4.3	2.8	1.8	1.3	1.0	0.8	0.5	0.2	53
All Cold Fronts	15.2	11.7	7.9	6.1	4.6	3.3	2.5	1.5	0.8	0.5	304

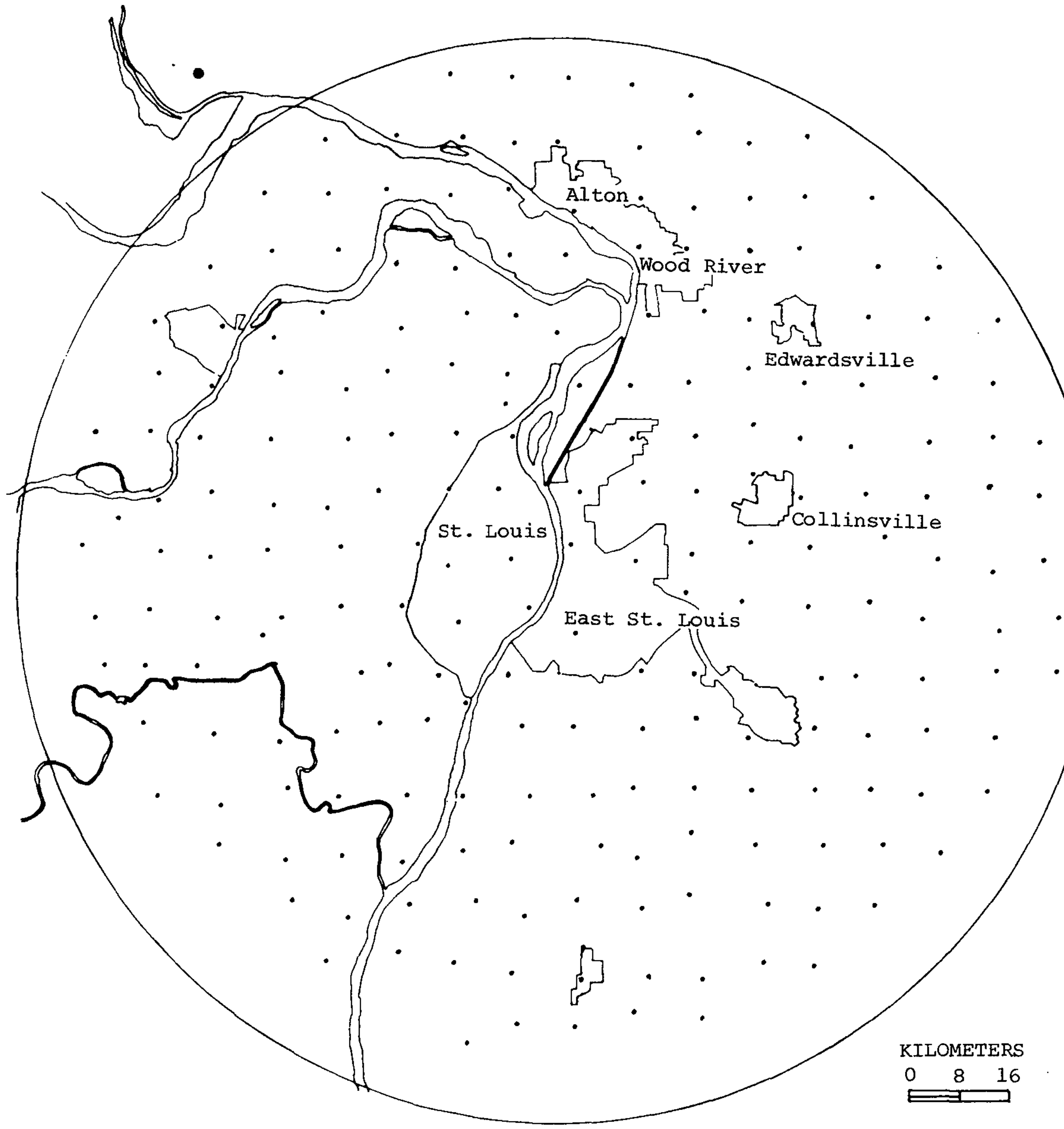

FIGURE 6. METROMEX RAINGAGE NETWORK

SURFACE RAINCELL MERGERS

Analyses were made of the characteristics of raincell mergers in the METROMEX Network during the summers of 1971-1975. Particular attention was given to differences in the frequency and locations of mergers in relatively wet and dry periods, since mergers are usually associated with increases in the intensity and areal extent of storm rainfall. It was of particular concern whether mergers were favored by inadvertent weather modification mechanisms, particularly urban influences, during dry periods (below-normal rainfall). If so, this would provide further evidence of the feasibility of enhancing storm rainfall during drought periods.

Results indicated a relatively strong tendency for mergers to occur most frequently in a major urban-effect area E and NE of St. Louis, along river valleys, and, to a lesser extent, in the more hilly regions of the METROMEX experimental area (Huff and Vogel, 1977). In general, there was a strong association between the spatial distribution of mergers and total monthly and seasonal rainfall. Location of maximum activity did not vary significantly between dry, wet, and near-normal months of rainfall.

Comparison of rainfall in regions of greatest merger concentrations indicated that the urban-related mergers tend to intensify the ongoing rainfall processes more than topographic-related mergers. Since merger processes (which are closely related to the rain enhancement processes) were found to be as active in dry as during wet months and are apparently stimulated by inadvertent weather mechansism, this is a favorable finding from the standpoint of planned weather modification. That is, it indicates that weather modification may stimulate rain production under favorable conditions during periods of agricultural water shortages.

COMPARISON OF WET AND DRY PERIOD PATTERNS ON METROMEX NETWORK

Data for the summers of 1971-1975 from the METROMEX Network of 225 recording raingages in 5200 km^2 were used to obtain very detailed comparisons of rainfall patterns in relatively wet, dry and moderate rainfall periods. This was done to assess differential effects of inadvertent weather modification on surface rainfall during such periods, with major emphasis upon dry period effects. The 15 summer months were divided into groups of five each to represent relative degrees of dryness and wetness, and some analyses were performed also on the three dryest and three wettest months. Investigation was made of both the frequency of rainy days and total rainfall in the three groups of months.

In general, results showed that inadvertent weather mechanisms energized by the urban environment and certain topographic features are operating under all types of precipitation climate (Huff and Vogel, 1977). During dry months, a trend for rainfall to occur more frequently along river valleys, in hilly regions and in heavily urbanized areas was noted. The heaviest rainfall during dry months also tended to occur in and downwind (east) of the St. Louis urban area and near certain topographic features. These findings are also favorable from the standpoint of weather modification potential, since they indicate enhancement of the natural rainfall during dry periods by weather modification forces (inadvertent in this case). The results also suggest that certain topographic and land use features (river valleys, hills, urban areas) are favorable regions to initiate weather modification activities during dry periods.

GENERAL CONCLUSIONS

1. Analytical results have been presented which describe the natural rainfall distribution in droughts of various severity in Illinois, a typical midwestern state. Relationships have been provided between storm mean rainfall, areal extent of storm rainfall, rainfall intensity, and drought size (severity) on the basis of frequency of occurrence. Synoptic weather conditions under which drought rainfall occurs most frequently, its diurnal distribution, and other factors pertinent to planned weather modification have been specified also. This information can then be used in evaluating weather modification potential and planning cloud seeding operations, provided that the weather modifier can specify his enhancement capabilities under various combinations of natural weather conditions, and the agriculturist can define the economic benefits that would be derived from the specified enhancement.

2. Various climatological analyses of rainfall characteristics in growing season droughts indicate that opportunities for alleviating agricultural water shortages through planned weather modification do exist. Despite the large deficiencies in total rainfall in these droughts, storms do occur that produce measurable rainfall on the average of once every four to five days in Illinois.

During the most critical months of July and August, 50% of the drought-associated rainstorms produce measurable rainfall (0.25 mm or 0.01 in.) over approximately 50% of the drought areas in the larger, more severe droughts extending over 50,000 km^2 or more within the state. In spot droughts encompassing areas of less than 5000 km^2, 50% of the drought storms produce measurable amounts over approximately 90% of the drought area.

The May-September droughts (as defined in this study) tend to incorporate more area, but to have less deficient rainfall than the mid-summer dry periods in July and August. In these droughts in Illinois, measurable rainfall was found to extend over approximately 70% of the drought area in 50% of the storms on large drought areas exceeding 80,000 km^2. In smaller area droughts encompassing less than 50,000 km^2, 50% of the storms produced measurable rainfall over approximately 90% of the drought region.

3. Assuming weather modification success is dependent largely upon enhancing ongoing rainstorms, substantial increases in the natural rainfall are most likely to be achieved through cloud treatment of organized storm systems, and in particular, cold frontal systems and their associated squall lines. These account for approximately 2/3 of the drought-period rainfall during July-August. Conversely, increases from treatment of non-organized air mass activity are likely to be negligible over an extensive drought

region, although some minor alleviation might be accomplished in small spots (a few farms, perhaps) within the overall drought region.

4. Seeding should be conducted on a 24-hour schedule in the Midwest; otherwise, a large portion of the storm enhancement opportunities is likely to be missed. For example, in Illinois approximtely 50% of the growing season rainfall occurs in the evening and night (1800-0600 CST) and 25% occurs from midnight to 0600 CST.

5. Analyses of METROMEX data provide additional evidence that weather modification should be successful to some degree, at least, in dry summers when agricultural water shortages develop. Analyses of inadvertent weather characteristics in the densely gaged network of 225 recording raingages in 5200 km^2 show that the spatial distribution patterns of raincell initiations, raincell mergers, and surface rainfall are similar in dry, wet, and moderate rainfall periods, and that the inadvertent processes are as active proportionally in dry as in wet periods. Dry periods appear to be caused to a large extent by a decrease in frequency of the more intense type of synoptic systems.

6. In evaluating the weather modification potential of cloud seeding operations, close attention should be given to the precipitation characteristics of the region to achieve realistic quantitative estimates. The use of the combination of storm mean rainfall probabilities and spatial distribution characteristics are especially helpful in making such estimates.

7. Precipitation climatological studies emphasizing those parameters which can be useful in the planning and evaluation of weather modification activities should be undertaken for various climatic regimes in the country.

ACKNOWLEDGMENTS

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