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Atmospheric Sciences Section
Illinois State Water Survey

INTERIM REPORT OF METROMEX STUDIES: 1971-1973

A Report to the Weather Modification
Program of the Research Applications
Directorate of the National Science Foundation

for

Grant GI-38317

Principal Investigator: Stanley A. Changnon, Jr.

Report Editor: Floyd A. Huff

SENIOR CONTRIBUTORS

Bernice Ackerman, Herbert Appleman, Stanley A. Changnon,
Floyd A. Huff, Douglas M. A. Jones, Paul T. Schickedanz, and John Vogel

September 1974
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CONTENTS

GLOSSARY

Urban-Effect Precipitation Event

A precipitation entity (raincell, rainstorm, thunderstorm, or hailstorm) which either develops over or passes across the urban-industrial areas of St. Louis or Alton-Wood River.

Hill-Effect Precipitation Event

A precipitation entity which develops over or passes across the Ozark Hills SW of St. Louis where development of convective activity is favored.

Bottomlands-Effect Precipitation Event

A precipitation entity which develops over or passes across the confluence of the Missouri and Mississippi Rivers NW of St. Louis and SW of Alton-Wood River where an abnormally high heat-moisture source frequently prevails.

No-Effect or Control Precipitation Event

A precipitation entity which does not come under the influence of either the urban or topographic influences described above, and, hence, is used for evaluation of the urban effect and topographic effects on rainfall in the research area.

Raincell

A closed isohyetal entity within the enveloping isohyet of a synoptic storm system consisting of one or more rainshowers or thunderstorms. Each shower or thunderstorm may be single or multicellular in a multicellular storm system, the raincell incorporates an isolated area of significantly greater intensity than the system-enveloping isohyet. In isolated single-cell storms, the raincell is uniquely defined by the separation between rain and no rain.

Rainstorm

An entity of rain (1 or more cells and/or areas of rain) in the network identified with a specific synoptic weather condition and separated from other entities by 20 miles and/or 1 hour between end and start times.

Thunder Period

Discrete periods with at least 2 peals of thunder heard per 15 minutes, that were separated from other thunder periods by 1 hour or longer of no thunder.

Hailstreak

An area of continuous hail having space-time continuity and representing at the surface an entity of hail produced in a storm.

Synoptic Weather Categories

Squall Line or Area: A rainstorm in which a definite trigger mechanism is evident; usually a short wave trough can be discerned in the lower troposphere. The convective activity associated with this type of system is intense, well organized, and marked by either a well-formed line or area.

Frontal: Precipitation which forms within 75 miles of a front (cold, stationary, or warm), and there is no evidence of it being associated with a squall system which might be moving in advance of a front.

Pre-Frontal and Post Frontal: Precipitation which occurs between 75 miles and 150 miles ahead of or behind a front.

Air Mass: No large scale synoptic causes are evident. The resulting convective activity is usually widely scattered to scattered and is weak. There is no well-organized area or line formation.

Low: A low pressure center so near the network that it is not possible to associate the precipitation with any frontal or mesoscale structure.

A. INTRODUCTION

S. A. Changnon, Jr. and F. A. Huff

Background

The general goal of the Illinois State Water Survey program involving METROMEX (METROpolitan Meteorological Experiment) consists of 1) the delineation of any anomalies in the precipitation and severe weather patterns and frequencies in St. Louis and environs, 2) the quantification of the causes for any such anomalies, 3) investigations of the relevance of these findings to the local area and to other urban-agricultural areas of Illinois, and 4) the transmission of these findings to potential users in the scientific community and to the public of Illinois. This broad, general goal of the Survey projects relating to METROMEX actually consists of 14 specific goals involving field operations and data collection, in-house analysis and research, and applications of the results to various users. Importantly, the Water Survey goals for METROMEX are being achieved by support from three sources: the National Science Foundation, the Atomic Energy Commission, and the State of Illinois.

The importance of the goals specifically served by those operations and research supported under this NSF Grant can only be fully appreciated in the context of the total Water Survey METROMEX program. The 14 goals and "activity" areas of the Water Survey program appear in Table A-1. A flow chart depicting these 14 goal-activity areas and how they interrelate appears in Fig. A-l. The means of information exchange and transmission are coded on this chart indicating the means by which data and finds will be exchanged between internal scientific activities and with "external" users. A more detailed discussion of goals has been provided by Changnon (1973).

The goals and activities addressed specifically by this grant, as identified in Table A-l and Fig. A-l, are #1 (identification of rainfall and severe weather anomalies); #2 (mapping of surface weather conditions); #3 (study of airflow); #6 (synoptic weather analyses); #7 (identification of the causes for anomalies); #8 (control measurements for prediction); #9 (local weather impact concerns); #11 (planning information); #12 (weather forecasting); #13 (applications to planned weather modification); and #14 (transfer of knowledge).

The thrust of the analysis on this grant in the past year has been in two compatible but separate directions. The principal approach used as revealed by the results in this report and elsewhere (Huff, 1973), is basically an all-data climatic-type evaluation. That is, rather large data samples for a month, a season, a year, or three years are studied as a whole and also by various meaningful space, time, and topical divisions (such as all rain with fronts, all rains at night, week-end versus weekday rainfall, etc .) . The other approach being employed consists of intensive meteorological studies

Table A-1. Specific Goals of METROMEX Program of the Illinois State Water Survey

Goals - Activity Areas	Period of Duration	Milestones	Application of Findings and Users
FIELD ORIENTED PROJECTS			
1. Study of surface rainfall and severe weather at St. Louis to define their time-space distributions and the presence of any anomalies.	5 Years (±1)	A	Goals 6, 7, 9, 11
2. Study of surface weather conditions (temperature, humidity, and winds) at St. Louis to define their time-space patterns.	5 Years (±1)	A	Goals 6, 7, 9, 11
3. Study of the airflow, circulation, and turbulence over St. Louis.	5 Years (±1)	A	Goals 6, 7, 9, 10, 11
4. Study of aerosols including their general sources, their transport using airflow measurements to clouds, and their deposition, both wet and dry, on the ground in the St. Louis area.	5 Years (±1)	A	Goals 5, 6, 7, 9, 10
5. Study of changes in surface and groundwater quality downwind of St. Louis.	2 Years (±1)	B	Goal 9
INTERNAL APPLICATIONS - ANALYTICAL PROJECT			
6. Meso-scale analyses of the synoptic weather conditions and atmospheric structure with precipitation events to classify events and relate sufrace conditions to precipitation processes.	5 Years	C	Goals 7 and 12
7. Identification and quantitative definition of the causes for the precipitation anomalies.	Last 4 Years	C	Goals 8 and 13, and other Metromex groups
8. Definition of the measurements critical to define urban anomalies and their causes in Metromex and at other cities.	5 Years	C	Goals 1-4, 7 and 11, and other Metromex groups.
EXTERNAL APPLICATIONS			
9. Identification of scientific and business concerns in local St. Louis area where anomalies have relevance.	Last 4 Years	D	City engineers, consulting engineers, water supply superintendents, local farmers and farm associations, . ecologists, and weather insurance companies. Goal 13 will also benefit.
10. Utilization of pollution data derived from any deposition studies.	Last 3 Years	D	Illinois and federal EPA officials, other air pollution studies (RAPS), and local pollution agencies.
11. Definitive information on weather-climatic changes, due to an urban-industrial area, available for local and regional planning.	Last 2 Years	D	City planners, engineers, and zoning boards.
12. Improvements in urban area forecasting of precipitation.	Last 3 Years	D	Meteorologists, (forecasters) in government and private practice.
13. Planning for purposeful weather modification experiments in Illinois.	Last 3 Years	D	Water Survey scientists, other Meteorologists contemplating rain and severe storm modification-projects, and Illinois Advisory Board on Weather Modification Control Statute.
14. Transfer of knowledge gained and new technologies developed to other scientists and other disciplines.	5 Years	D	The scientific and engineering communities.

(1) Milestones

A - Goal - Activity Areas 1-4 are basically 5-year ongoing projects. They have annual (spring) milestones after data processing and initial analysis sufficient to detect measurement gaps. The final milestone involves summary, interpretation, and presentation of results to other users.

B - Has an annual milestone involving review of first year results and re-design (if needed) of second year measurements. Final milestone is completion, summary, and translation of information to users.

C - These studies have 1-year milestones, each aimed at summarizing and reviewing all past results, and the final milestone is the summarization and conclusion of the studies.

D - These activities are basically continuous efforts largely related to user identification, communication of initial results to users, feedback of suggestions from users, and then final communication of findings and results. The only milestone is their completion.

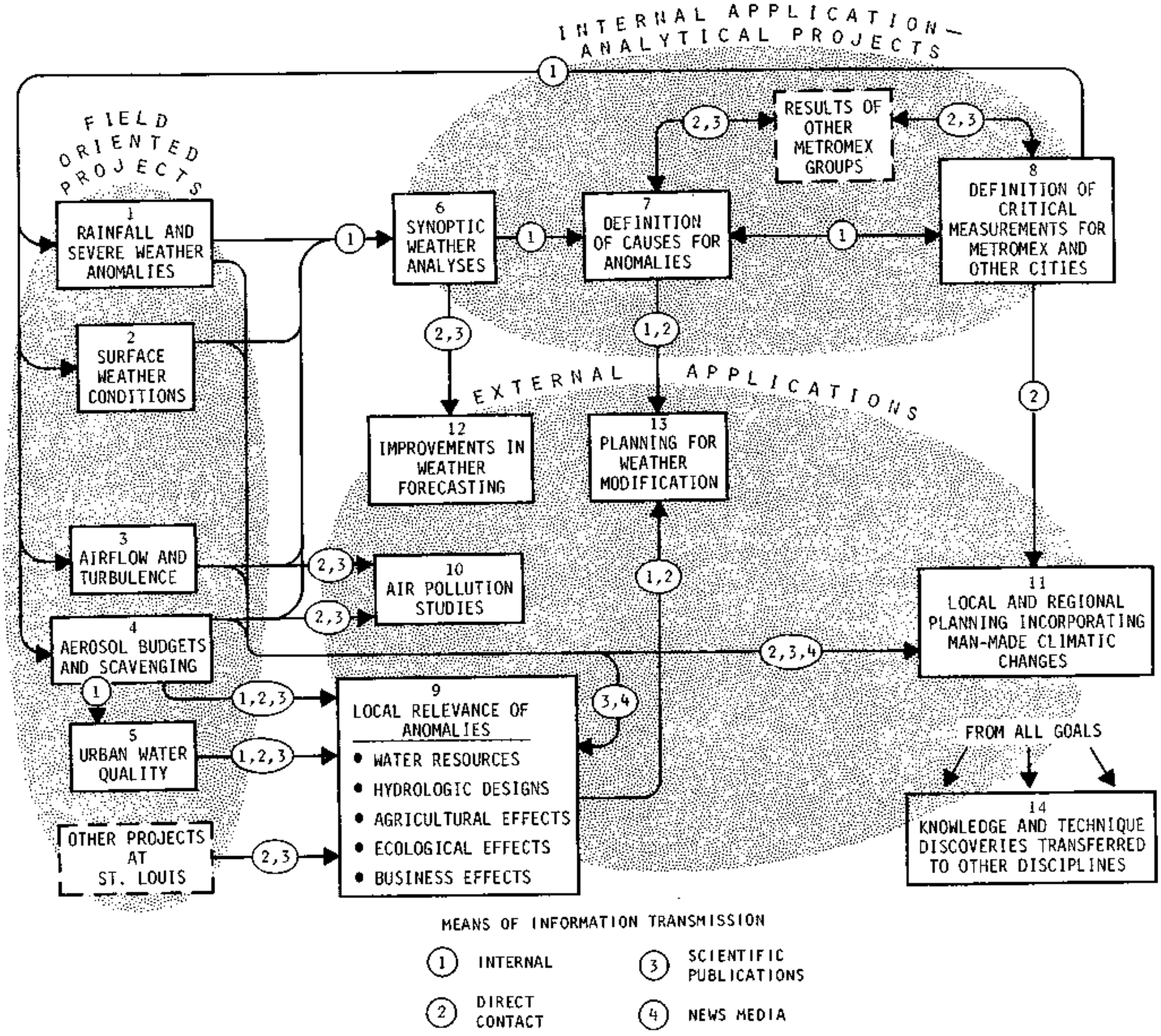

Figure A-l. Interaction of Water Survey METROMEX goal-oriented projects with their internal and external applications of individual periods, usually days, of varying precipitation conditions. This case study effort was pursued vigorously in 1973-74 and a report will be published in 1974 presenting these results.

Scope of Report

This interim report summarizes activities and analytical results obtained in conjunction with the 1973 (summer) METROMEX operations. Where possible, a summary of results for the 3-year period, 1971-73, is presented also. Particular emphasis has been placed upon the radar analyses, since 1973 was the first year in which adequate data were collected to aid substantially in delineating the urban effect on precipitation processes. More attention also has been given to surface air and dewpoint temperature patterns than in earlier reports, since more and better data have become available, and these parameters are assuming increasing importance as a result of findings in our case studies for the 1971-73 period (to be presented in another report). Revision of some of our - earlier findings has become necessary as a result of more detailed and thorough synoptic analyses performed on the 1973 data and re-analysis of the 1971-72 synoptic weather systems using the 1973 typing method. The final section of the report is an in-depth recounting of the transmission of project results to users during 1973. This indicates publications and talks resulting from the project.

Personnel

This report has resulted from the cooperation of staff members involved in the NSF supported METROMEX program. Each contribution is authored by the principal analyst/s involved in the particular study, but numerous others contributed to the work in each case. Professional staff members who materially contributed to the success of this project through their field and/or analytical efforts but who were not authors of sections of this report, include David Brunkow (electrical engineer), Mark Gardner (electrical engineer), William Mansell (meteorologist), Donald Staggs (electronics engineer), and Neil Towery (meteorologist). Others who contributed to the field projects and data processing included Edna Anderson, John Brothers, Marion Busch, Eberhard Brieschke, Marvin Clevenger, Wilbur Debolt, Arthur Sims, Phyllis Stone, Ileah Trover, Dan Watson, and Yueh Liu.

Many students have also contributed to this project, and 46 undergraduate and graduate students of the Atmospheric Sciences have gained invaluable training as project employees. The number of students employed in the 1971-73 period include 15 for weather radar operations, 28 for weather observations, 8 for electronic instrument operations and maintenance, 12 for pibal wind operations, 11 for operations of radiosondes, and 24 for analyses of basic data. The 3-year total is 98 students.

The report was prepared under the general supervision of William C. Ackermann, Chief of the Water Survey, and under the direction of Stanley A. Changnon, Jr., Head, Atmospheric Sciences Section. Floyd A. Huff, analysis supervisor on NSF GI-38317, was responsible for organizing, editing, and assembling the report.

Facilities and Instrumentation

Facilities and instrumentation used in 1971 and 1972 operations have been described in detail by Changnon (1971) and Huff (1973). The thunder observational network was increased from six sites in 1972 to ten in 1973 in order to determine better the downwind extent of the urban effect. Otherwise, the 1972 and 1973 observational networks were essentially the same. The 1973 raingage network consisted of 245 gages that included 224 within the research circle and 21 in a less dense array to the NE and E of the circle. The hygrothermograph network consisted of 25 stations, and seven wind recorders were operated. There were 11 pibal stations in operation, and radiosondes were taken at three sites. The two radars, FPS-18 and TPS-10, continued to operate from the Pere Marquette Headquarters in 1973.

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B. SYNOPTIC ANALYSES

John L. Vogel

Introduction

An important facet of the METROMEX investigation is to determine what weather processes are active over the research area throughout all rain periods; especially important are those processes which are active during the formative stages of each rain period. To achieve this goal the synoptic and large mesoscales surface features primarily responsible for each rainstorm were identified. A rainstorm, for the purposes of this investigation, was defined as an entity of measurable rain in the network identified with a specific synoptic weather condition and separate from other entities by 20 miles and/or 1 hour between end and start times. The main goals of this synoptic weather analysis are to provide information pertaining to:

1. Aid in the forecasting of urban weather,
2. Defining those urban processes which actively contribute to the modification of weather,
3. Delineating rainstorms for special cases studies, and
4. Establishing an urban synoptic climatology.

It was recognized that surface fronts are difficult to define during the summer months (June, July, and August), so all relevant surface and upper air data were analyzed prior to and during each rainstorm. This was done with more detail than the National Weather Service could possibly provide with their national weather FAX products. In many instances, certain synoptic and mesoscale features were followed on an hourly basis. Each rainstorm was classified according to one of the following definitions:

Squall Line (SL) or Area (SA): A definite trigger mechanism was evident, and, usually a short wave trough could be discerned in the lower troposphere. The convective activity associated with this type of system was intense, well organized, and marked by either a well-formed line or area.

Frontal (CF, WF, SF): Precipitation formed within 75 miles of a front (cold, stationary, or warm), and there was no evidence of it being associated with a squall line or squall area which might be moving in advance of a front.

Pre-Frontal (P) and Post Frontal (PF): Precipitation occurred between 75 miles and 150 miles ahead of or behind a front.

Air Mass (AM): No large scale synoptic causes were evident, and the resulting convective activity was usually widely scattered to scattered and weak. There was no well-organized area or line formation.

Low (L): A low pressure center located so near to the network that it was not possible to associate the precipitation with any frontal or mesoscale structure.

A similar classification scheme was used by Morgan and Beebe (1973) to determine what large scale weather features were causing rainstorms over the METROMEX Network. There are two basic differences between the present scheme and the one used by Morgan and Beebe. They are 1) the frontal zone in the present system extends 75 miles either side of the front compared to a 50-mile zone either side of the front in the previous classification, and 2) a clearer distinction has been made between squall lines and squall areas. The latter improvement has added a definite class to distinguish from squall lines and air mass activity. As a result, organized areas of showers and thunderstorms are now distinctly separated from the more intense squall lines and the scattered air mass showers. Therefore, it was necessary to re-analyze completely the first two summers of METROMEX synoptic data and the analysis of the summer of 1973 has been added. It is hoped that this classification scheme will help to isolate those synoptic situations which interact with the urban circulation and alter the pattern of precipitation over and downwind from an urban complex.

Results of Analyses

During the first three years of METROMEX there were a total of 180 objective rainstorms. These included 47 rainstorms on 40 days in 1971, 68 rainstorms on 43 days in 1972, and 65 rainstorms on 44 days in 1973. The classification of these storms by year and synoptic category, as determined from the above set of definitions, are shown in Table B-1. During the summer of 1973, the most frequent individual classification was air mass, followed closely by squall areas, squall lines, and cold fronts. All other classes occurred less than 5 times. Combined, the squall areas and squall lines had more occurrences than the air mass classification, and they accounted for over 40% of all rain occurrences during the summer of 1973.

Comparing the synoptic classes between years, it is readily apparent that there was little difference between 1972 and 1973. However, there was a significant difference between the synoptic classes of 1971, a dry year, and the other two years. Eventhough the number of rain days for the three summers were approximately the same, there was a significant difference in the number of air mass cases. In 1971 there were only 6 air mass storms compared to more than 20 in both 1972 and 1973 which were somewhat wetter years.

The total rainfall, the percent of total rainfall, and the amount of precipitation per synoptic event for 1972 and 1973 are presented in Table B-2. During the summer of 1973 an inch of rain or less was received from all synoptic classes except squall areas or squall lines. The most important single contributor of any synoptic class was the squall line, which totaled 6.47 inches of rain or nearly 67% of the summer's rainfall. Squall areas accounted for an additional 16% of the total rainfall, so that the total rainfall from organized lines or areas of precipitation, separated from fronts, was nearly 83% or 8.01 inches. The next most important class was cold fronts which produced a total of 0.76 inch over the network, or only 7.9% of all objective rainstorms. The remaining synoptic classifications warm fronts, stationary fronts, pre- and post-frontal, air mass and lows, contributed less than 10% of the total rainfall during the summer of 1973.

Table B-1. Frequency of Synoptic Types

	SL	SA	CF	WF	SF	P E PF	AM	L	Total Storms	Total Raindays
1971	5	17	7	1	5	4	6	2	47	40
1972	11	10	6	3	4	9	24	1	68	43
1973	12	16	6	3	2	2	21	1	65	44

Table B-2. Comparison of Synoptic Types with Rainfall

	Total Rainfall (inches)		% of Total Rainfall		Rainfall/Synoptic Event	
	72	73	72	73	72	73
SL	4.25	6.47	55.5	66.8	0.39	0.54
SA	1.10	1.54	14.4	16.0	0.11	0.10
CF	1.30	0.76	17.0	7.9	0.22	0.13
WF	0.13	0.24	1.7	2.5	0.04	0.08
SF	0.44	0.22	5.7	2.3	0.11	0.11
P£PF	0.08	0.31	1.0	3.2	0.01	0.08
AM	0.35	0.12	4.6	1.2	0.01	0.01
L	0.01	0.01	0.1	0.1	0.01	0.01
	7.66	9.67				

As would be expected, the most intense rains occurred with squall lines with an average intensity of 0.54 inch per occurrence in the research circle. The air mass rainstorms and those rains associated with lows (only 1 instance in 1973) experienced the lowest intensity per rain event, 0.01 of an inch; in fact, the average intensity of the air mass storms averaged just barely more than a trace of rain (0.005 inch) over the whole network. The intensities of the remaining synoptic classes were all clustered around 0.10 inch. Cold fronts were a poor second at 0.13 inch per storm.

As shown in Table B-2 the 21 air mass storms, or nearly one-third of all rainstorm occurrences in 1973, only accounted for 1.2% of the total rainfall. Eventhough air mass storms occurred more frequently than any other synoptic class they only represented a very minor portion of the total summer rainfall in 1973.

The largest difference between the summers of 1972 and 1973 was that two more inches of rain fell in 1973 than 1972. Nearly all of this difference was realized from squall lines. The average squall line in 1972 delivered 0.15 inch less rain per event in 1972 than in 1973. This means that due to the difference in average intensity each squall line occurrence in 1973 delivered an average of 17,600 more acre-ft of rain over the basic raingage network of approximately 2100 mi^2.

The overall distribution of synoptic classes in 1972 and 1973 were similar and only minor differences between the two years can be perceived in Table B-2. The largest differences in the two years occurred between squall lines and cold fronts. In 1972, squall lines accounted for a total of 55.5% of the total rainfall, whereas squall lines accounted for 66.8% of the total rainfall in 1973. In 1972, cold fronts, instead of squall areas, were the second most prolific rain producer. However, squall systems (both area and lines) and cold fronts accounted for almost 87% of all the rain in 1972, whereas in 1973 these three synoptic classes accounted for nearly 91% of all the rainfall.

It becomes apparent that if the city of St. Louis is acting to modify the precipitation over and downwind, the major interaction between the urban-industrial complex and the passing rainstorms must be occurring in the more intense rainfalls. If inadvertent weather modification were occurring with air mass storms, or with any of the other synoptic classifications which only contribute minor amounts to the overall precipitation pattern in and around the St. Louis region during the summer, augmentation on the order of severalfold would be required to obtain significant amounts of the magnitude shown by Huff and Changnon (1972). This indicates that the greatest potential for inadvertent weather modification related to the urban-industrial complex of St. Louis during the summer must occur with the stronger, more intense synoptic events, such as exist with squall areas, squall lines, and cold fronts.

Figure B-1 depicts the total rainfall for the objective storms in 1972 and 1973. The mean rainfall for the research circle during these two summers was 17.34 inches. The 1971 rainfall is not shown because at the time of this writing it was unavailable for analysis.

There were three major rainfall centers during these summers, all located downwind from the city of St. Louis, and the maximum value of all three centers were within 0.03 inch. The three highs were situated over Edwardsville, Granite City, and near Belleville. With southeasterly moving storms, the Edwardsville high would be downwind from the Alton-Wood River area, and the Belleville high would be downwind from St. Louis. With easterly movements, both Granite City and Belleville would be downwind from St. Louis. Edwardsville and Granite City would be downwind from St. Louis

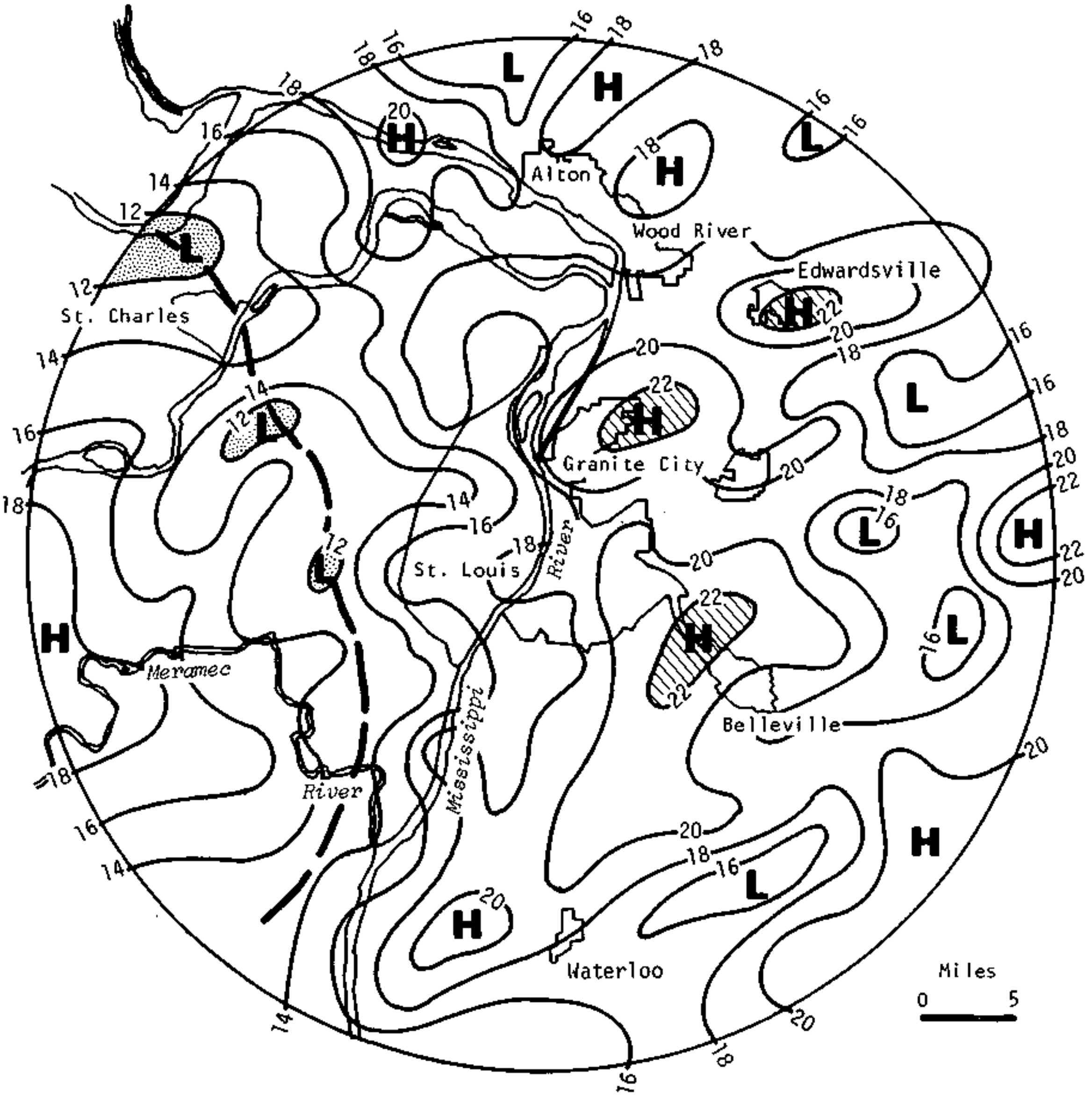

Figure B-1. Total rainfall (inches) for objective storms, 1972-1973 with storms moving from the southwest. A minor isohyetal high was situated west of Waterloo, and this center was probably associated with rainstorms and rainsystems which moved from the Ozark foothills to the south of the Meramec River. Another high was located northwest of Alton.

A major trough in the rainfall pattern was located from north of St. Charles, across west St. Louis county, to the vicinity of the confluence of the Mississippi and Meramec Rivers. There are several other minor perturbations in the rainfall pattern shown in Fig. B-1, but these additional highs and lows are quite near the mean rainfall for the basic research circle.

In an effort to determine which synoptic classes contribute the most rainfall to the downwind maximums observed in Fig. B-l, the amount of rainfall that fell during storms of each synoptic type were determined. The rainfall pattern that resulted from squall systems (squall lines and squall areas combined) is illustrated in Fig. B-2. The mean rainfall contribution for squall systems during the summers of 1972 and 1973 was 13.36 inches, or 77% of the total rainfall for the two summer seasons. The major center during this 2-year period was located at Granite City, and its central value was more than 6 inches greater than the network mean. A secondary maximum was located at Belleville. This maximum and the Granite City center are part of a general maximum of rainfall immediately east of St. Louis, and both centers contribute a substantial portion of the total rainfall observed in these two areas. A line of highs extended from northwest of Alton, across northwest St. Louis county to the city of St. Louis. This group of maximum values correlates quite well with a similar ridge in the overall rainfall pattern of Fig. B-l. A trough of. lower values extended from north of St. Charles to the mouth of the Meramec River, and this corresponds to a similar trough found in Fig. B-l.

The total rainfall for cold fronts storms is shown in Fig. B-3. The mean rainfall for the 2-year period of 1972 and 1973 was 2.06 inches. The major rain center during this period was concentrated over and slightly east of the Edwardsville region where over 5 inches of rain fell. This constituted over 20-25% of the total rainfall in this region. A secondary precipitation maximum was located northeast of Waterloo in the southern part of the network. The major low of rainfall noted in this instance extended on an east-west line from East St. Louis to the Missouri River near the edge of the research circle.

Eventhough the air mass storms only contributed a total of 0.47 inch, about 2%, to the overall total of the mean rainfall for the 2-year period, there was a total of 45 air mass storms which are nearly 34% of all the rainstorms that occurred during this time. The rainfall pattern for air mass storms is presented in Fig. B-4. The major rainfall center in this classification was located northwest of Waterloo, just east of the mouth of the Meramec River. The hills may well have been the area in which the original clouds were initiated in this instance, with the rainfall being deposited well to the south of the city of St. Louis. This would be reasonable, since the air mass classification is quite often characteristic of a situation in which the winds in the lower levels of the atmosphere are light southwest to west. Therefore, to try and determine where the original system was initiated one must look upstream, not

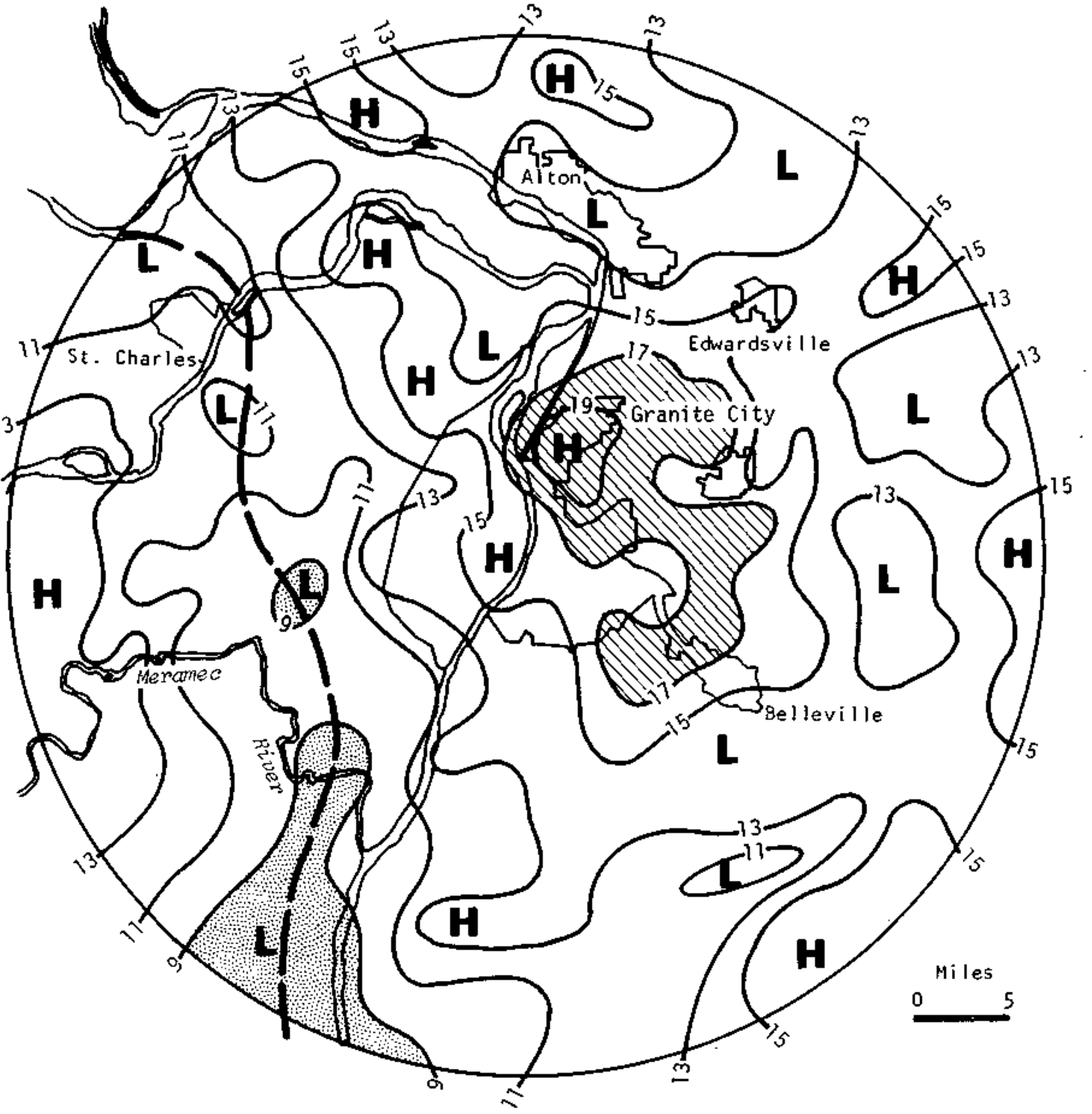

Figure B-2. Total rainfall (inches) in squall area and squall line storms, 1972-1973

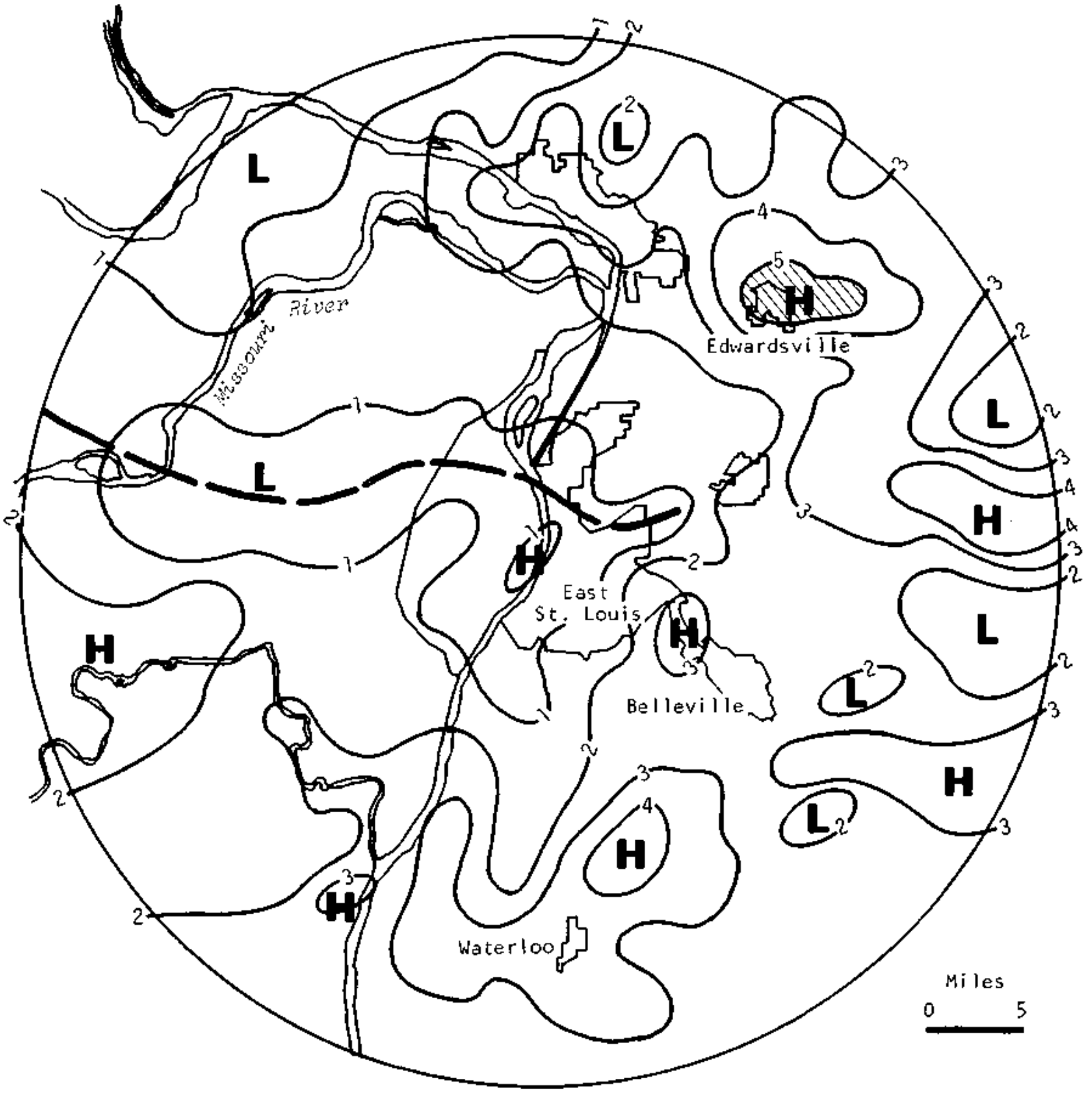

Figure B-3. Total rainfall (inches) in cold front storms, 1972-1973

Figure B-4. Total rainfall (inches) in air mass storms, 1972-1973 directly overhead of the rainfall maximum, because it takes time for the rainstorm to mature from a small cumulus cloud to a cloud large enough to precipitate.

A secondary rainfall maximum in air mass storms can be noted over Alton-Wood River, with some very minor precipitation maxima over Edwardsville, Collinsville, and east of Belleville. One must also note that the majority of the rainfall due to air mass storms falls once again on the east side of the Mississippi. The lowest values observed in Fig. B-4 during this 2-year period were noted over the city of St. Louis and over the area immediately west of the city, in a highly urbanized region of St. Louis. One implication which might be drawn from the resultant pattern is that the city has just that little extra bit of heat and stability which may hinder the development of weak convective storms by raising there convective temperature. As a result, these clouds would tend to have higher bases over the city, a phenomena that has been observed and reported by Cataneo (1973). Measurements of cloud bases were made by an aircraft and it was found that the clouds which formed over the city were, on the average, 2000 feet higher than those which developed over rural environments.

Summary and Conclusions

There was little difference in the synoptic classification between 1972 and 1973. However, 1971, a very dry year, had about 20 less rainstorms, although all three summers recorded precipitation on 40 to 44 days over the raingage network. The largest difference in terms of actual synoptic classes was that there were about 20 less air mass storms during the summer of 1971, than during the wetter summers of 1972 and 1973.

Over a third of the total storm cases for the summers of 1972 and 1973 were composed of air mass storms, but these storms contributed less than 3% of the total rainfall during these two years. During the same time, squall lines, squall areas, and cold fronts accounted for nearly 89% of the total network rainfall. This would indicate that the greatest potential for inadvertent weather modification due to an urban-industrial complex exists during the stronger, more intense synoptic events.

The overall rainfall pattern for the 2-year period, 1972 and 1973, indicated three rainfall maximums, and all three of these highs were downwind from the St. Louis urban-industrial complex. The rain patterns which resulted from squall lines, squall areas, and cold fronts imply that if the city is causing a maximum of rainfall in the downwind area, it indeed is attributable to these more intense synoptic situations. The 2-year resultant air mass pattern implies that rainfall which results from these synoptic situations can not possibly account for the 10% increase in rainfall downwind from St. Louis reported by Huff and Changnon (1972) in their long-term climatic study. Therefore, one can only conclude that the more active and intense the synoptic situation, the greater the chances are that the city will effectively enhance the precipitation.

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C. 1973 ANALYSES OF MONTHLY, SEASONAL, AND STORM RAINFALL WITH SUMMARY OF 1971-1973 FINDINGS

F. A. Huff and E. E. Schlessman, Jr.

Introduction

As indicated in an earlier report (Huff and Schlessman, 1973), the distribution of monthly and seasonal rainfall, occurrences of measurable rainfall, and heavy rainstorm occurrences are being studied as part of the METROMEX Project. This is being done 1) to establish the location and intensity of potential urban effects on the regional rainfall, 2) to investigate potential urban-induced increases in the number of rain events, and 3) to ascertain to what extent urban effects are present when the natural rainfall is relatively heavy. Analyses are made pertaining to potential urban effects 1) with varying wind directions prior to onset of rain, 2) with different types of synoptic weather conditions (fronts, squall lines, air mass storms, etc.), and 3) during different times of the day (diurnal effect). In the following paragraphs, results of various 1973 analyses will be described, and overall findings for the 1971-1973 operational period will be briefly summarized.

Monthly and Seasonal Rainfall Distributions

During the summers of 1971 and 1972, the heaviest rainfall occurred east of the Mississippi River. Heaviest amounts in 1971 were recorded in the Edwardsville-Wood River area and in 1972 in the region from Edwardsville to Collinsville to Belleville. This resulted in a two-summer high that exceeded 24 inches in the Edwardsville area, which frequently lies downwind of either the St. Louis or Wood River urban-industrial complexes, depending upon the wind flow and storm movements (see Huff and Schlessman, 1973). Similarly, a low of less than 10 inches was located west of St. Louis in a region that is usually upwind of potential urban effects. Thus, the potential for an urban-induced increase in rainfall appeared strong at the end of 1972.

Summer 1973. A major change occurred in the 1973 summer rainfall pattern which is shown in Fig. C-1. In the region of the Edwardsville high, the summer totals were 90 to 100% of normal. The heaviest rain centers were located in the immediate urban-industrial region of Granite City and at the western edge of the network. The Granite City center is potentially urban-effected, but the western high cannot be attributed to urban-induced rain increases. Overall, the rainfall averaged 11.72 inches east of the Mississippi compared with 11.87 west of the river, which is usually upwind of potential urban-industrial effects. The network average was 11.79 inches which is 103% of the normal of 11.44 inches, based upon long-term records of NWS stations in the area. During 1971 and 1972, the network means were 63% and 69% of normal, respectively. Thus, two below-normal and one near-normal seasons have been experienced during the three summers of network operations.

Figure C-1. 1973 summer rainfall, in inches

The 1973 pattern resulted from one above-normal, one near-normal, and one below-normal month. The June rainfall of 5.46 inches was 1.09 inches above normal, whereas the July rainfall of 3.62 inches was 0.03 inch above normal, and the August total of 2.71 inches was 0.77 inch below normal. Summer 1973 amounts exceeded 18 inches and were more than 50% above normal at the center of the two major highs in Granite City and on the western edge of the network (Fig. C-1). The lowest amounts (less than 8 inches) were less than 70% of normal. It is of interest to note that the Granite City high was primarily the result of very heavy rainfall (over 8 inches) in the relatively dry month of August. However, this occurrence does not reflect any trend for the potential urban-effect highs to be strongly related to below-normal rainfall. An examination of 1971 and 1972 monthly data showed that most of the potentially urban-effected highs received their heaviest rainfall in those months when the network means were relatively high.

Figure C-2 shows the 3-summer rainfall pattern for 1971-1973. The primary high was in the Edwardsville area where the 3-summer total exceeded 36 inches at two raingages. The major low was W and SW of St. Louis where less than 21 inches were recorded at three stations. Secondary highs are located in other potential urban-effect areas, such as the Granite City-Collinsville region and north of Alton-Wood River. However, these secondary highs were equalled by highs in several other regions of the network, such as the bottomlands area at the bend of the Missouri River in Fig. C-2, in the Ozark foothills at the extreme western edge of the network, and in the southern and southeastern parts of the network.

The most pronounced indication of an urban effect continues to be in the Edwardsville area, as concluded after each of the preceding two seasons of METROMEX operations. The 3-summer rainfall in the Edwardsville high of Fig. C-2 was over 30% above the network mean for this period, whereas the low centers W and SW of St. Louis recorded approximately 75% of the network mean rainfall for the 3-summer period. The minor highs mentioned above recorded 3-summer totals that were 10-12% above the network mean.

Frequency of Measurable Rainfall

Calculations are being made of the number of occurrences of measurable rainfall (≥0.01 inch) at each raingage during network storms. This is done to search for evidence that the urban environment causes an increase in the number of rain events, which, in turn, could be a primary cause of urban-induced highs in the rainfall pattern. However, the combined results for 1971-1972 provided no strong evidence of any substantial increase in the number of rain events from urban-induced effects (Huff and Schlessman, 1973). The 1973 data support the above conclusion. The 3-summer pattern still presents a random-type distribution of highs and lows of nearly equal magnitude throughout the network. For example, a 3-summer total of 85 occurrences was recorded NE of Collinsville where urban effects would be likely to occur. However, similar frequencies were recorded 10 to 15 miles west of St. Louis, in the Missouri River bottomlands NW of St. Louis, and in the extreme SE part of the network.

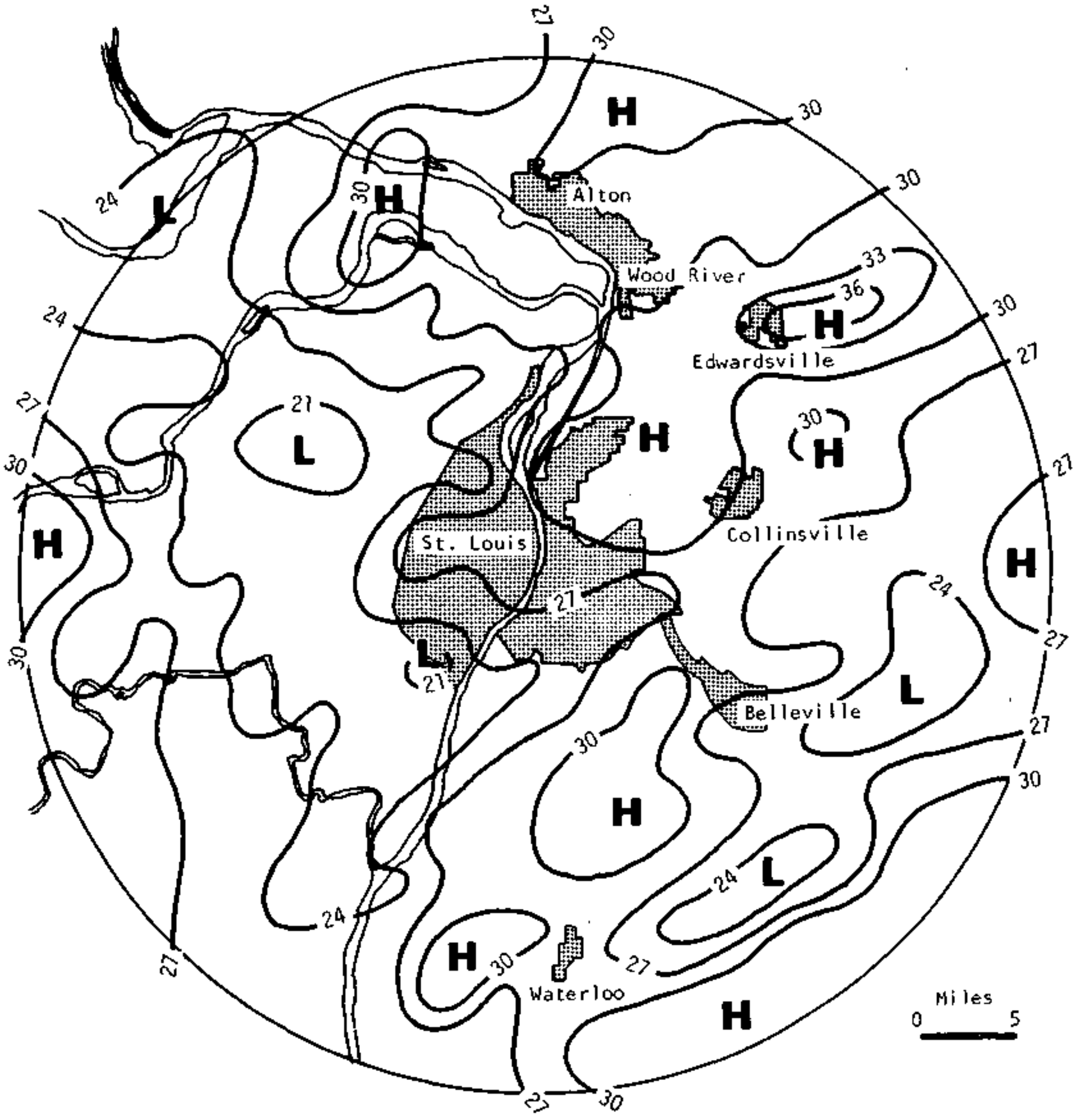

Figure C-2. Total summer rainfall for 1971-1973, in inches

Distribution of Heavy Rainstorms

A heavy rainstorm is defined as one in which one inch or more of rainfall is recorded. The 1971-1972 combined results (Huff and Schlessman, 1973) showed the most frequent occurrence of these storms just E and NE of Edwardsville, and this corresponded closely with the major center of total rainfall for the two summers. It was also found that over 60% of the rainfall in this total rainfall center occurred in the one-inch storms. As a result, it was concluded that intensification of existing storms was a major cause of the seasonal highs in this region during 1971-1972, and that this could very well be related to an urban-intensification mechanism acting upon naturally occurring storms.

The results of the 1973 analysis showed a rather random distribution pattern of one-inch storms throughout the network. As expected, one of the high centers, in which several stations had six occurrences of heavy storms, was located in the Granite City area where a seasonal maximum in network total rainfall was recorded. However, five occurrences were recorded at two stations in the Edwardsville area where the 1971-1972 high frequency existed. Other areas of high frequency corresponded quite closely with the rainfall highs of Fig. C-1.

The 3-year pattern of one-inch storms is shown in Fig. C-3. In the Edwardsville center, 50% of the 3-summer rainfall occurred with these storms and 15 to 18% of all storms recorded one-inch or greater amounts in this region. Both of the above percentages are maxima for the network. The frequency in the Edwardsville high (12-13) is approximately double the network mean of six occurrences. As indicated earlier, this area is frequently downwind of either St. Louis or Alton-Wood River depending upon storm movements.

Weekday-Weekend Occurrences of Rainfall

In the 1971-1972 analyses, weekday-weekend relations were developed for the entire network as a unit area. However, previous climatic studies (Huff and Changnon, 1972) and the 1971-1972 METROMEX studies indicate that the major urban effect maximizes E-NE of St. Louis and ESE of Wood River. Therefore, the research circle was divided into four quadrants for more precise evaluation of possible weekday-weekend differences in the frequency of measurable daily rainfall.

From previous findings, a greater weekday frequency, if present in the 1971-1973 summers, would be expected to occur in the NE quadrant which has been most frequently downwind of the potential urban-effect areas. Also, the seasonal rainfall for the 1971-1973 period has maximized in this quadrant of the research circle that is centered at the St. Louis Arch. The SE quadrant would be expected to be the second most frequently affected area. The NW and SW quadrants would be expected to be least affected by the urban environmental influences, especially the SW quadrant which would only be subject to urban-generated effects with northeasterly winds.

Figure C-S. Number of storms with rainfall ≥ 1.00 inch during summer of 1971-1973

Results of the quadrant analysis for each of the three summers and for the 3-summer period combined are summarized in Table C-1. With no urban influence on the daily frequency of rain occurrences, 71% would occur, on the average, on weekdays and 29% of weekends. Table C-1 shows only the SW quadrant with more weekday rain occurrences (73%) than normally expected (71%) for the three summers combined. The NE quadrant where a weekday excess would most likely occur from urban effects had a below-average expectancy with 69% of the 1971-1973 rainfalls on weekdays. The NW and SE quadrants were also slightly below average for the 3-summer period.

In only one of the three summers (1971) did the NE quadrant show an above-average expectancy of weekday occurrences (72%). The SW quadrant was above average in two summers (1971, 1973), the NW quadrant once (1971), and the SE quadrant in none of the three summers. Overall, it must be concluded from the quadrant analysis that there is no evidence in the 1971-1973 data of an increased frequency in rainy days due to the greater industrial activity on weekdays. If anything, there is slight evidence of a weekend maximization of rain occurrences in the downwind areas.

Table C-1. Frequency of Rainfall on Weekdays and Weekends in the Four Quadrants of the METROMEX Network during Summers of 1971-1973

	Southwest		Northwest		Northeast		Southeast	
	No.	%	No.	%	No.	%	No.	%
					1971			
Weekdays	30	75	28	76	26	72	25	71
Weekends	10	25	9	24	10	28	10	29
					1972			
Weekdays	28	68	26	63	27	64	29	67
Weekends	13	32	15	37	15	36	14	33
					1973			
Weekdays	32	74	31	69	31	70	32	71
Weekends	11	26	14	31	13	30	13	29
					1971-1973			
Total	124	100	123	100	122	100	123	100
Weekdays	90	73	85	69	84	69	86	70
Weekends	34	27	38	31	38	31	37	30

In view of the above findings, it was decided to make an additional analysis of weekday-weekend relations in which the frequency of daily rainfall was computed only for the immediate urban areas of St. Louis and Alton-Wood River. For this purpose, eight raingage stations were available in St. Louis and six in Alton-Wood River. If urban effects produce only very light rainfall in certain weather conditions, these light rains could frequently dissipate before leaving the immediate urban area and, therefore, would not be reflected properly in the average statistics for the four quadrants presented in Table C-l.

Results of the urban analysis are summarized in Table C-2. This table shows a reverse of the trend indicated in Table C-l and agrees better with results of earlier climatic studies (Huff and Changnon, 1972). In both urban areas, 73% of the total rain days in the 1971-1973 period occurred on weekdays, compared with a normal expectation of 71%, and with 69% in the NE quadrant of Table C-l where the urban effect was expected to maximize. Alton-Wood River had an above average number of weekdays with rain in all three summers, and St. Louis was above average in two of the three years.

Table C-2. Frequency of Rainfall on Weekdays and Weekends in Alton-Wood River and St. Louis Immediate Urban Areas During Summers of 1971-1973

	Alton-Wood River		St. Louis	
	No.	%	No.	%
		1971		
Weekdays	22	73	23	77
Weekends	8	27	7	23
		1972		
Weekdays	23	72	25	69
Weekends	9	28	11	31
		1973		
Weekdays	24	73	26	74
Weekends	9	27	9	26
		1971-1973		
Total	95	100	101	100
Weekdays	96	73	74	73
Weekends	26	27	27	27

Diurnal Distribution of Summer Rainfall

The diurnal distribution of summer rainfall for 1971-1973 was studied to obtain information on whether the potential urban effects tend to be more pronounced during certain periods of the day. If so, this would provide indirect evidence of the involvement of combinations of diurnal and urban heat outputs in the urban-induced effects on downwind rainfall.

The diurnal rainfall distribution was examined by calculating the amount of rainfall by 3-hour periods during the 1971-1973 summers and the percentage of the 3-summer rainfall total occurring in each 3-hour period. Examination of the 3-hourly diurnal maps showed that the most rainfall, and, consequently, the highest percentage of the 3-summer total occurred in the late afternoon, 1500-1800 CDT. During this 3-hour period, the network averaged 24,5% of the total 3-summer precipitation. With an even diurnal distribution, 12.5% would be expected to occur in each 3-hour period.

Further examination of the diurnal rainfall patterns showed that the most pronounced diurnal excess in the 1500-1800 period was in the urban area of St. Louis, including the urban-industrial regions on both the west (St. Louis proper) and east sides of the river. The variations in percentage of total rainfall in each 3-hour period is illustrated in Table C-3 in which the diurnal percentages of the 3-summer rainfall are shown for selected raingaging stations. These locations were selected to include 1) regions where urban enhancement has been identified, 2) potential breeding areas for convective clouds outside of the urban region, 3) the region of minimum summer rainfall west of St. Louis, and 4) a relatively high rainfall region observed in the SE quadrant of the METROMEX Network which may be associated with the Ozark Hills to the west and southwest.

Reference to the percentages in Table C-3 shows the greatest percentages in the 1500-1800 period in the St. Louis and East St. Louis urban areas, where 3-station averages of 36.9% and 40.6%, respectively, occurred in the 1971-1973 summers. The maximum percentages of 42.8 and 42.6 were recorded at Gages 133 and 151, respectively, which are located in the Centreville region where an earlier climatic study by Huff and Changnon (1972) indicated a peak in the urban rainfall enhancement.

The maximum total rainfall for the 3-summer period (Fig. C-2) occurred near Edwardsville which is frequently downwind of both the St. Louis and Alton-Wood River urban-industrial areas. Gages 50 and 51 (Table C-3) show the diurnal maximum at 1500-1800, but the percentage is not as large as in the immediate urban area of St. Louis. All selected regions in Table C-3 show a maximum in the 1500-1800 period, except for the Alton region (Gages 20, 12) where the maximum shifts to early evening.

Table C-3 shows considerably more variation in the time of minimum rainfall compared with maximum occurrences. The 3-hour minimum varies between 0000-0300, 0300-0600, and 1200-1500. In the urban-industrial area of St. Louis, the 3-year minimum occurred in early afternoon, 1200-1500 CDT. Most other regions had their minimim in the early morning hours. The minimum immediately preceding the pronounced maximum in the St. Louis area is another indication of the importance of diurnal heating in triggering the urban effect, whether the cause is primarily dynamical or microphysical. Changnon and Huff (1957) in a study of cloud distributions in Illinois found that summer cumulus occur most frequently in southwestern Illinois (Springfield) in the 1200-1500 period, but that cumulonimbus develop most often in late afternoon. Thus, the unusually high proportion of the summer rainfall in the 1500-1800 period in the immediate urban area of St. Louis suggests an urban enhancement effect superimposed upon the natural diurnal effect.

Table C-3. Diurnal Distribution of 1971-1973 Summer Rainfall, in Percent of Total Rainfall

Station and	Percent of Total 3-Season Rainfall for 3-Hour Periods							
Location	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24
Wood River to Edwardsville and Eastward								
47	7.5	6.0	9.8	9.6	10.1	22.9	20.4	13.7
50	10.1	4.5	10.2	5.4	15.2	22.9	17.3	14.4
51	11.2	6.1	8.2	5.0	15.3	21.9	13.8	18.5
Mean	9.6	5.5	9.4	6.7	13.5	22.6	17.2	15.5
Bottomlands to Alton and Northeastward								
29	6.4	6.2	7.6	7.1	8.9	23.5	22.5	17.8
20	6.9	5.7	13.3	6.7	12.7	16.2	27.2	11.3
12	7.9	5.5	10.4	5.3	14.6	13.4	25.1	17.8
Mean	7.1	5.8	10.4	6.4	12.1	17.7	24.9	15.6
St. Louis Urban Area								
96	5.7	5.8	9.3	11.3	6.1	31.8	12.6	17.4
113	5.4	5.6	8.9	16.3	5.1	38.8	9.2	10.7
131	6.5	6.7	10.4	9.3	4.8	40.1	12.3	9.9
Mean	5.9	6.0	9.5	12.3	5.3	36.9	11.4	12.7
East St. Louis Urban Area								
115	7.2	4.1	5.0	11.0	3.9	36.5	13.2	19.2
133	6.5	7.2	10.2	9.5	2.2	42.8	12.6	9.0
151	5.4	7.1	6.3	8.7	9.8	42.6	11.6	8.5
Mean	6.4	6.1	7.2	9.7	5.3	40.6	12.5	12.2
Granite City and Northeastward								
80	4.2	6.1	8.9	7.4	6.1	30.5	15.5	21.3
81	3.1	5.2	10.1	5.9	14.3	26.3	15.6	19.5
64	4.0	5.8	11.9	5.6	21.5	22.4	15.8	13.0
Mean	3.8	5.7	10.3	6.3	14.0	26.4	15.6	17.9

Table C-3. (Continued)

Station and Location	Percent of Total 3-Season Rainfall for 3-Hour Periods							
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-214
East St. Louis to Collinsville and Eastward								
115	7.2	4.1	5.0	11.0	3.9	36.5	13.1	19.2
101	4.0	7.4	8.7	5.2	21.2	22.1	16.8	14.6
103	7.9	14.2	10.7	4.7	17.4	16.0	18.2	10.9
Mean	6.4	8.6	8.1	7.0	14.1	24.9	16.0	14.9
Major Low West of St. Louis								
72	8.6	7.3	16.1	8.9	6.5	25.7	16.7	10.2
73	7.4	5.4	10.3	7.1	5.9	35.1	18.7	10.1
92	5.9	6.7	12.0	6.8	4.2	32.4	19.6	12.4
Mean	7.3	6.5	12.8	7.6	5.5	31.1	18.3	10.9
Ozark Hills Southwest of St. Louis								
159	4.9	11.4	9.7	8.3	6.5	25.5	14.1	19.6
176	8.5	9.5	13.7	12.9	7.0	24.8	11.9	11.7
191	10.8	9.9	9.9	5.0	22.3	21.7	9.6	10.8
Mean	8.1	10.3	11.1	8.7	11.9	24.0	11.9	14.0
Southeast Quadrant High								
197	10.7	9.9	5.6	9.7	10.8	21.9	17.4	14.0
217	14.7	8.6	6.9	6.9	13.7	25.6	11.2	12.4
227	10.0	16.2	7.4	5.0	14.1	25.7	7.7	13.9
Mean	11.8	11.6	6.6	7.2	12.9	24.4	12.1	13.4

In general, the diurnal findings for 1971-1973 are essentially the same as indicated by Huff and Schlessman (1973) from analysis of 1971-1972 data. The outstanding late afternoon maximum in the St. Louis region is likely related to a combination of natural diurnal heating and urban thermal-aerosol outputs. Conditions favorable for the development of convective activity in upwind feeder regions are also likely involved in positioning of the 1500-1800 maximum. These feeder regions are the Missouri-Mississippi confluence northwest of the city (hot, humid bottomlands) and the Ozark foothills southwest of the urban area.

Wind-Rainfall Relations in 1973

The 1973 rainstorms were grouped according to the prevailing surface winds prior to the start of rainfall. The length of the prior period depended upon the wind speed, but averaged approximately three hours. All rainfall on the network associated with prevailing winds from the SW quadrant (180°-269°) were combined to provide a network rainfall pattern with winds from this direction. Similar maps were developed for prevailing winds from the NW, NE, and SE sectors.

Next, the network was divided into four quandrants starting at the network center. The percentage of the total summer rainfall in each network quadrant associated with each of the four prevailing wind groups was then determined. The results are summarized in Table C-3.

Evidence of an urban effect upon enhancement of the network rainfall is very pronounced in Table C-3. Thus, with winds from 0°-89° the maximum urban effect would be expected to occur in the SW quadrant of the network. Although only a small percentage of the network rainfall occurred with these prevailing winds, the maximum percentage occurred in the SW quadrant with 5.8% of the summer rainfall compared with less than 3% in the other quadrants.

Similarly with winds from 90° to 179°, the urban effect should be most pronounced in the NW part of the network, and this is verified by Table C-3, where the maximum of 60.5% was recorded in the NW quadrant. With winds from 180°-269°, the expected maximum would be expected to occur in the NE part of the network, and this is verified by Table C-3. With NW winds, the urban enhancement should maximize in the SE quadrant of the network, as shown in Table C-3. Thus, with all four prevailing wind groups, the rainfall percentage maximum occurred in the network quadrant expected in the presence of an urban rainfall enhancement effect.

The foregoing analysis provides additional evidence of the presence of an urban rainfall enhancement mechanism, and indicates that the enhancement is strongly related to the low-level wind flow. A similar analysis for the 3 years combined, 1971-1973, could not be presented at this time, since the revised storm definition has not been applied to the 1971 storms. This will be done in the near future.

Table C-3. Relation Between Prevailing Surface Winds Prior to Start of Rain and Total Rainfall During Summer 1973

Prevailing Wind Direction (degrees)	Average Percent of Total Rainfall in Given Network Quadrant			
	NE	SE	SW	NW
0-89	0.6	2.6	5.8	2.9
90-179	49.0	52.1	50.9	60.5
180-269	49.1	41.0	42.1	36.2
270-359	1.3	4.3	1.2	0.4

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D. METROMEX RAINCELL STUDIES FOR 1971-1973

Paul T. Schickedanz

Introduction

One of many methods being used to evaluate the effect of the urban-industrial complex on precipitation in METROMEX has been the analysis of surface raincells (Schickedanz, 1972, 1973b). The data for surface raincell analysis have been obtained from the METROMEX network (Changnon et al., 1971; Changnon, 1973) of recording raingages which has an area of 2,100 mi^2 and a density of 9.4 mi^2/gage. The resulting raincell analysis is being used to identify the precipitation characteristics that are being altered by the urban-industrial complex. These altered characteristics are determined by isolating individual raincells (patterns of rain usually produced by a single convective entity) and determining their history as to initiation, movement, maximization, duration, size, and total rain production. The chief advantages of this technique include 1) the spatial portrayal of a cell - the smallest definable rain producing entity, and 2) the description of several cell parameters which provide means to infer how physical processes have been changed by the urban area. Objective definitions for cells and analytical procedures have been developed to minimize subjectivity for cell delineation (Schickedanz, 1972, 1973b). Large portions of the analysis have been computerized, so as to expedite handling the vast quantity of data.

In this report, the characteristics of surface raincells are used 1) as a *descriptive tool* for demonstrating the magnitude, structure, and characteristics of the urban-industrial influence on rainfall, and 2) as an *investigative tool* for exposing and explaining causes of the altered precipitation. For details concerning rationale, analytical procedures, and statistical considerations of the raincell approach, the reader is referred to Schickedanz (1973b). The primary purpose of this report is to present results obtained from the analysis of the 1973 METROMEX data. However, to explain adequately results for 1973, it is informative to compare these results to those of previous years. Thus, results from 1971-1972 are also included.

Analytical Procedure

A raincell was defined in the following manner: *a raincell in a multicellular system is a closed isohyetal entity within the overall enveloping isohyet of the rain-producing system; that is, it defines an isolated area of significantly greater intensity than the background rainfall. When raincells develop apart from a multicellular storm system, there is no background rainfall, and the single cell is uniquely defined by the separation between rain and no rain.*

The delineation of these cells requires several steps. First, 5-minute rainfall amounts are digitized directly from the raingage charts (weighing bucket gages) and these are entered on punch cards through the use of a Model 3400 X-Y digitizer (Autotrol). The digitized amounts are converted to 5-minute rates and then processed by the IBM 360 computer so that a 5-minute printout of rainfall rates is obtained. The 5-minute rates and pre-determined contour intervals are then plotted by the computer.

From the 5-minute isohyetal maps, a determination of which rainfall entities constitute a raincell must be made. This determination is made using the definition; however, a size restriction on the area, an intensity restriction on the rainfall rate, and a time restriction on the initiation and dissipation of cells are necessary. These restrictions include: 1) a cell cannot envelop more than 1/3 of the area of the background isohyet, 2) a cell can be delineated by rainfall rate when the difference between its smallest point value and the background isohyetal equals or exceeds a rate of 0.75 in/hr, and 3) in order for a cell to initiate, it must be present longer than 5 minutes. These definitions and procedures provide a semi-objective method of cell delineation. It should be noted that these definitions were developed after much inspection of the rain data, and many "trial and error" attempts at defining a large number of raincells of varying characteristics.

The raincells as defined in this manner represent the rainfall intensity cores on 5-minute maps. In the multicellular system, the cores are usually much smaller than the total rain area. These cores are imbedded in the surrounding background rainfall and do not represent the total storm rainfall produced by the storm system during a 5-minute period. The restrictions on area, size, and duration were designed to separate these cores from their surrounding isohyets (background isohyets) so that alterations in their characteristics (volume, area, mean, duration, etc.) could be evaluated in relation to urban and industrial areas where they developed and/or passed. This definition of cells implies that most of the urban rainfall effect will be exhibited within these rainfall cores as opposed to the general background rainfall.

The background isohyet may vary from one 5-minute period to the next in order to permit the delineation of the raincell (rain core) according to definition. This is required because the background rainfall is constantly increasing and decreasing in intensity and a constant background isohyet would not permit the tracing of cells from one 5-minute period to the next. However, the definition provides a high degree of consistency from map-to-map, because the same spacing of isohyets is used for every 5-minute period (Schickedanz, 1972).

Urban-Induced Alterations Indicated by Basic Stratifications

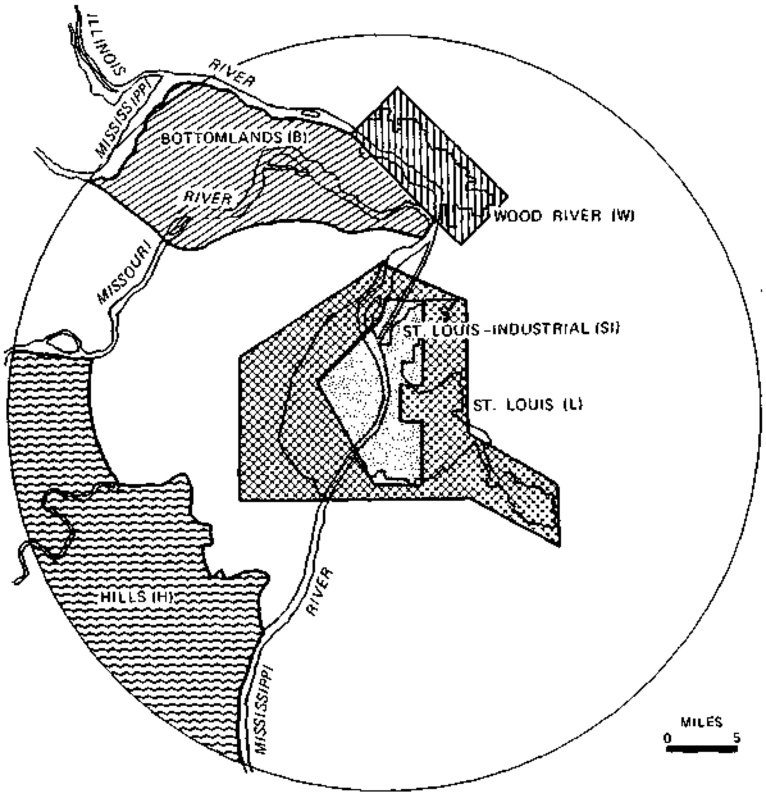
In a previous report (Schickedanz, 1973b), emphasis was placed on the results of the "third-order stratification". This stratification has subsequently become the "basic" stratification of the raincell analysis and was used extensively in a paper by Schickedanz (1974). This basic stratification is performed by classifying the raincells in relation to their position within one of several areas: the St. Louis source area (L), the Wood River source area (W), the hill source area (H), and the bottomlands source area (B) shown in Fig. D-1. The L area is a potential source of heat nuclei, turbulence, and, possibly, moisture (treatment agents) for the atmosphere; the W area is considered to be a nuclei source (CCN and ice) and likely a moisture source from cooling towers, but having a lesser thermal perturbation than St. Louis; the H area is a potential source of convective development due to hill effects (lifting, turbulence, differential heating); the B area is considered a major heat and moisture source due to marshy land in the confluence of the Missouri and Mississippi Rivers. Further details concerning the rationale of this selection of source areas are discussed by Schickedanz (1974).

All cells which develop in and/or cross a given source area, but are never exposed to any of the other three areas, are designated "effect" cells for that area. Cells which never contact any of the four effect areas (L, H, W, B) were considered control (C) or "non-effect" cells. Also, cells which are exposed to both L and H, or to both W and B are treated as two more classes of effect cells. In addition, a sub-area was selected from the L area as being representative of major nuclei sources within the L area. This sub-area (labeled St. Louis-Industrial) had Aitken nucleus production rates of 150×10^4 nuclei cm^{-2} sec^{-1} during August 1971-1972 according to Auer and Dirks (1974). All cells which occur in this St. Louis-Industrial area (SI), but never in the H, W, or B areas, are designated as SI effect cells.

Many of the cells are not completely contained within the network. The analyses that follow are restricted to complete cells, that is, cells which go through their complete life histories within the boundaries of the raingage network. The sample sizes of complete cells for each of the basic stratifications are listed in Table D-l. For the 1971-1973 period, the control stratification had the largest number of cells, and the St. Louis stratification had the second largest number. The differences in sample sizes among the various stratifications are largely due to the differences in areal size (St. Louis, 300 mi^2; St. Louis-Industrial, 66 mi^2; Wood River, 66 mi^2; Hills, 168 mi^2; Bottomlands, 140 mi^2; and Control, 1260 mi^2). There were 1,092 effect cells and 1,596 non-effect cells for a total of 2,688 complete cells (SI cells are excluded from these totals because they are a sub-sample).

Cell rain volume is employed extensively in this report because rain volume is the single, most important parameter insofar as the ultimate benefit of enhancement or suppression of rainfall is concerned. This parameter represents the total water output by the cell and is an integrated measure of the other cell parameters and of the various atmospheric conditions which produced the cell. Results from the comparison of 1,092 effect cells and 1,596 non-effect (control) cells according to cell volume are listed in Table D-2.

Since all effect values are compared to the control values, the validity of the control values is important. Therefore, a comparison was made of these mean control (natural) values to those obtained in an earlier study of unmodified raincells. Huff and Schickedanz (1970) obtained a median value of 110 acre feet for raincells on a dense rural network in extreme southern Illinois. When we



Figvre D-1. Hypothesized regions of potential treatment agents

Table D-1. Comparison of Sample Size and Number Density from Effect and Non-Effect Raincells (complete cells)

	Areas where Cells Developed and/or Passed					
	St. Louis (L)	St. Louis-Industrial (SI)	Wood River (W)	Hills (H)	Bottom-lands (B)	Control (C)
			Sample Size			
1971	119	45	30	29	56	285
1972	209	77	40	46	74	585
1973	274	93	67	64	84	726
1971-73	602	215	137	139	214	1596
			Number Density (# cells/mi^2)			
1971	0.44	0.69	0.46	0.17	0.40	0.21
1972	0.77	1.18	0.61	0.27	0.53	0.43
1973	1.01	1.42	1.02	0.38	0.60	0.53
1971-73	2.22	3.28	2.09	0.83	1.52	1.18

consider that different techniques were used to delineate the raincells," the agreement of the 3-year control value of 114 acre feet with this previously derived value is quite good. This agreement lends support to the validity of using the described control values in the various comparisons.

Inspection of the volume data in Table D-2 indicates that cells occurring in the urban-industrial areas produced the largest percentage differences. The percent differences of cells were 172% for St. Louis (L), 266% for St. Louis-Industrial (SI), 179% for Wood River (W), 91% for the Hills (H), and only 14% for the Bottomlands (B). The percentage increase in the L and W cells was approximately twice that of the H cells, and the percentage increase in the SI cells was approximately three times that of the H cells. The largest increase in the Hill cells occurred in 1973, which was the wettest year. This agrees with the findings of Jones et al., (1974) who concluded that the effect of small hills on rainfall in southern Illinois was the greatest during the heaviest rains, particularly those totaling more than two inches during the warm season of the year.

The differences between the urban-industrial effect cells (L, W, SI) and the control cells would seem to represent alterations of dramatic proportions. It is of interest to compare these percentage increases with those obtained for single cloud seeding in Florida. Simpson et al., (1973) states, "The single-cloud seeding factor on rainfall is virtually conclusively established as positive, in the vicinity of three." Thus, the increases in the L cells and those in the W cells are very comparable to Simpson's results for single cloud seeding, since these increases indicate "seeding" factors in the vicinity of two or three.

Table D-2. Comparison of Average Raincell Parameters from Effect and Non-Effect Raincells

	Areas where Cells Developed and/or Passed					
	St. Louis (L)	St. Louis-Industrial (SI)	Wood River (W)	Hills (H)	Bottom-lands (B)	Control (C)
			Volume (acre/ft)			
1971	215(113)*	254(151)	409(305)	191(89)	107(6)	101
1972	372(210)	518(332)	416(247)	179(49)	153(28)	120
1973	303(163)	413(259)	217(89)	257(123)	125(9)	115
1971-73	310(172)	417(266)	318(179)	218(91)	130(14)	114
			Mean (inches)			
1971	.08(14)	.07(0)	.14(100)	.11(57)	.06(-14)	.07
1972	.11(38)	.13(62)	.11(38)	.09(12)	.09(12)	.08
1973	.15(67)	.17(89)	.13(44)	.14(56)	.09(0)	.09
1971-73	.12(50)	.14(75)	.13(62)	.12(50)	.08(0)	.08
			Area (mi^2)			
1971	40(90)	50(138)	34(62)	33(57)	26(24)	21
1972	44(100)	53(141)	37(68)	28(27)	26(18)	22
1973	30(58)	37(95)	24(26)	22(16)	20(5)	19
1971-73	37(85)	45(125)	30(50)	26(30)	24(20)	20
			Duration (minutes)			
1971	27(29)	30(43)	26(24)	23(10)	24(14)	21
1972	33(38)	35(46)	27(12)	29(21)	24(0)	24
1973	28(22)	34(48)	24(4)	25(9)	24(4)	23
1971-73	30(30)	34(48)	26(13)	26(13)	24(4)	23

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* Effect-control difference expressed as % of control in parentheses.

The above findings illustrate one of the basic difficulties involved in evaluating weather modification experiments. Dramatic increases are often obtained in single cloud experiments, but the increase over the entirety of a region is often quite small and difficult to evaluate. In this instance, dramatic increases apparently occur in rain entities (i.e., raincells) but the apparent increase in the general rainfall pattern in the Edwardsville high during 1971-1972 (the major downwind high) was on the order of 20-30% (Huff and Schlessman, 1973).

One reason that the raincells have a greater percentage increase (266%) than the apparent increase (20-30%) within regions of the research circle is due to the nature of the derived cellular rainfall. Overall, the cellular rainfall (rain cores) from complete cells in 1973 represents only 21% of the total summer rainfall pattern and the incomplete cells plus the non-cellular rainfall (background) represent 79%. The percentage values for rainfall from complete cells were 35% for the L area, 40% for the SI area, 26% for the W area, 10% for the H area, 18% for the B area, and 20% for the C area.

When incomplete cells (cells not completely contained in network) are included with the complete cells, the total cellular rainfall represents 34% of the total storm rainfall and the non-cellular rainfall represents 66%. The percentage values for total cellular rainfall were then 36% for the L area, 41% for the SI area, 37% for the W area, 35% for the H area, 30% for the B area, and 34% for the C area. If rainfall modification is most effective in cellular rainfall (rain intensity centers) as opposed to non-cellular rainfall, these results imply that the rainfall increase over a region will of necessity be small even with large increases in individual rain entities. However, the cellular rainfall generally describes the overall rainfall pattern in 1973. Within some of the major rainfall highs, percentage values are as high as 50%. For example, in the L area during 1973, point percentage values within the Granite City high reach 56%.

The average values for means, areas, and durations of the effect and non-effect cells are also listed in Table D-2. In general, cells in 1972 had the greatest volumes, the largest durations, and the largest areas, but not the largest means. With the exception of the W area, the 1973 cells had the largest means but the smallest areas. The summer of 1973 was the wettest of the three summers, and these findings indicate that the intensity of cell rainfall was the greatest during this summer (i.e., large mean rainfall over small areas).

There was a tendency for individual raincells to exhibit greater movement in 1972 than in 1973. This tendency is illustrated in the total rain pattern of the SI cells which is shown on Fig. D-2 for 1972 and on Fig. D-3 for 1973. In 1972 the 2-inch isohyet extended from the Granite City area into the Collinsville area, indicating greater movement and areal extent of cells. Also, the 0.01-inch isohyet covered a much larger area in 1972 than in 1973. Thus, cells in 1972 had a movement pattern which deposited rainfall in the area of the Collinsville high (Huff and Schessman, 1973). Cells in 1973 were more confined to the city and a very intense core occurred in the Granite City area (seven inches). Similarly, the 1972 Collinsville high was non-existent in the 1973 rainfall pattern, but an intense rainfall high occurred in the Granite City area (see Section C).

Each summer was progressively wetter than the previous summer during the period 1971-1973. This trend is in direct contrast to the trend in percent differences of volumes and durations in the W cells shown in Table D-3. That is, the W cell parameters generally decrease as the summers become progressively wetter.

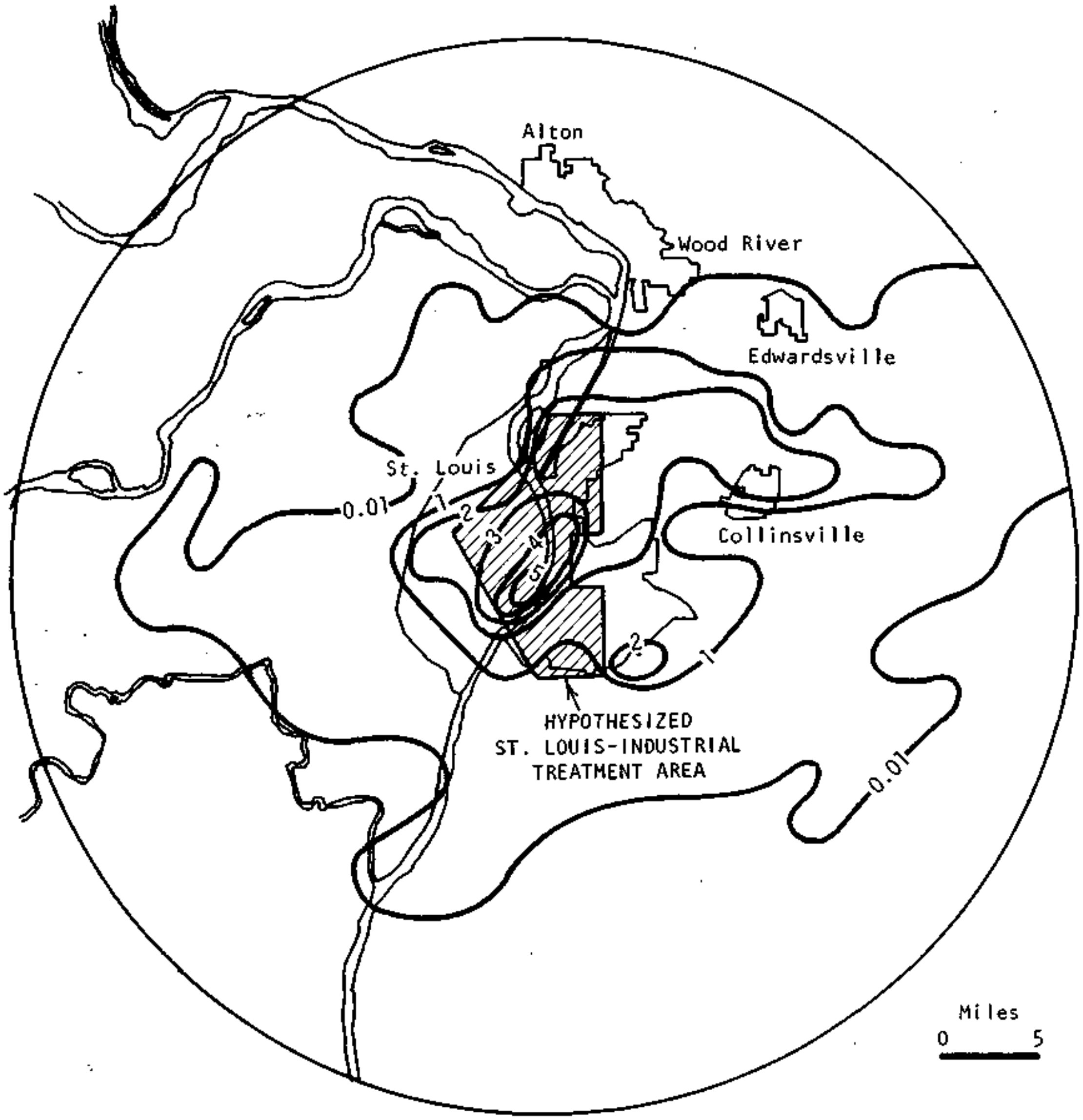

Figure D-2. Rainfall pattern for cases which developed and/or passed through the St. Louis-Industrial area during the summer, 1972 (complete cells only)

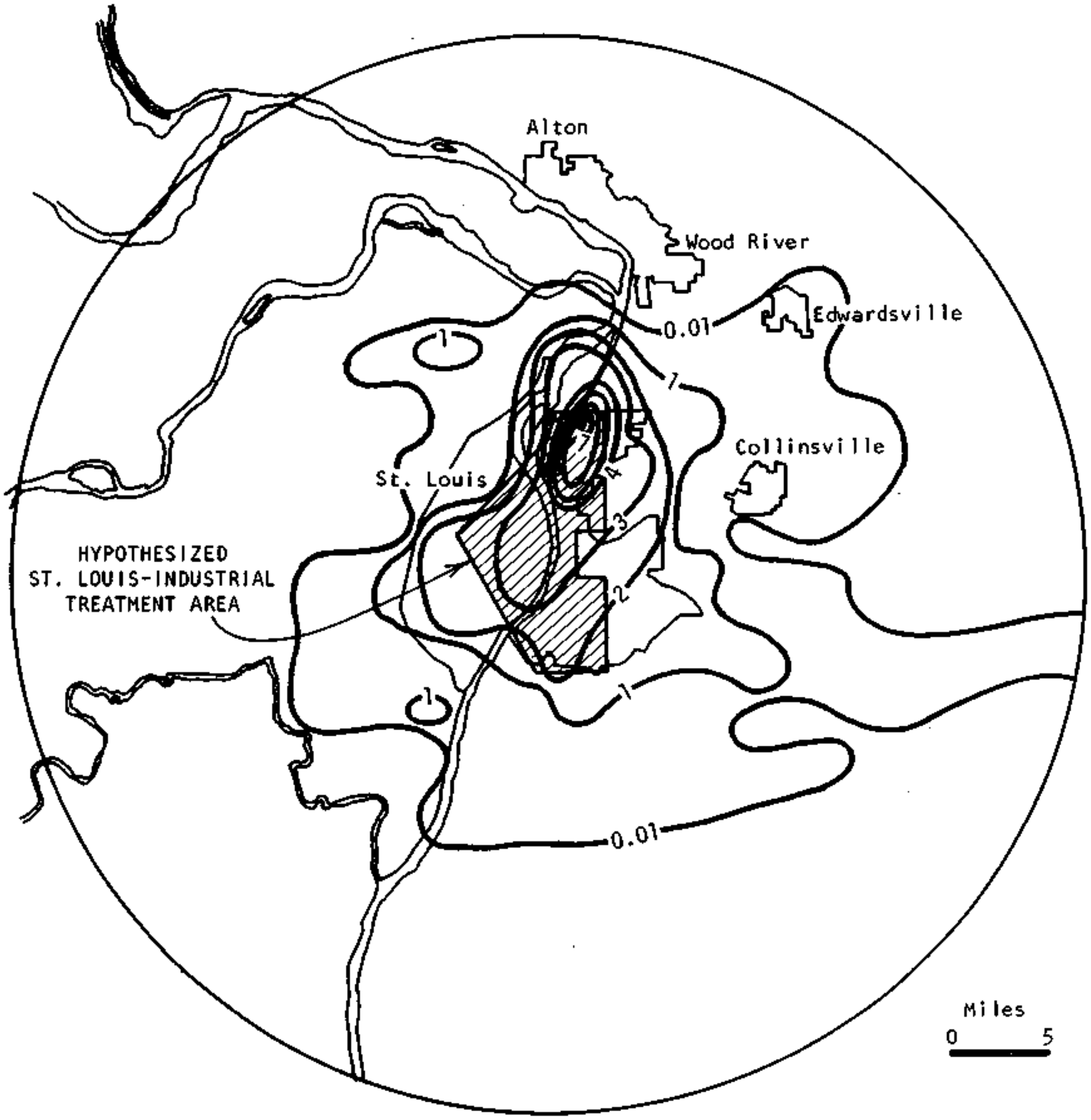

Figure D-3. Rainfall pattern for oases which developed and/or passed through the St. Louis-Industrial area during the summer, 1973 (complete cells only)

Table D-3. Comparison of Average Volume from Effect and Non-Effect Cells Stratified According to Path Length

	Areas where Cells Developed and/or Passed					
	St. Louis (L)	St. Louis-Industrial (SI)	Wood River (W)	Hills (H)	Bottom-lands (B)	Control (C)
			≤ 4 mi.			
1971	69(25)*	75(36)	92(67)	111(102)	28(-49)	55
1972	114(90)	133(122)	95(58)	63(5)	104(73)	60
1973	128(73)	152(104)	135(82)	99(34)	79(7)	74
1971-73	112(70)	128(94)	114(73)	90(36)	75(14)	66
			≤ 8 mi.			
1971	134(61)	128(54)	142(71)	161(94)	67(-19)	83
1972	152(69)	140(56)	99(10)	104(16)	131(46)	90
1973	219(126)	253(161)	158(63)	141(45)	120(24)	97
1971-73	181(97)	190(107)	139(51)	133(45)	110(20)	92
			≤ 12 mi.			
1971	172(89)	177(95)	291(220)	157(73)	107(18)	91
1972	255(138)	301(181)	120(12)	107(0)	150(40)	107
1973	247(138)	325(212)	185(78)	212(104)	123(18)	104
1971-73	235(128)	285(177)	190(84)	166(61)	128(24)	103
			All Cells			
1971	215(113)	254(151)	409(305)	191(89)	107(6)	101
1972	372(210)	518(332)	416(247)	179(49)	153(28)	120
1973	303(163)	413(259)	217(89)	257(123)	125(9)	115
1971-73	310(172)	417(266)	318(179)	218(91)	130(14)	114

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* Effect-control difference expressed as % of control in parentheses

For the L and SI cells the percentage increase of mean rainfall was greater as the summers became progressively wetter. However, this trend was not present in the Wood River cells and suggest the possibility of a different underlying physical relationship (or sampling differences). If real, this might be attributed to differences in nuclei and/or thermal structure between the two urban-industrial areas.

One of the problems inherent with the raincell analysis is how to evaluate cells not completely contained in the network. Because of this problem, the analysis was restricted to cells that were completely contained. The restriction of the analysis to complete cells presents the possibility that the data may be biased toward the effect cells. This bias may occur because St. Louis is located in the center of the research circle, and, thus, has the greatest opportunity to sample the heavier, longer-moving raincells.

Also, there is the problem of positively skewed rainfall distributions. In fact, the volume data are well fitted by the log-normal distribution, which clearly indicates that these are positively skewed distributions. With these distributions there is the possibility that a few large raincells may dominate the sample to the extent that the difference between an effect and control sample rainfall may be solely the result of these cells. These cells may frequent a particular area instead of another simply by random chance and lead to erroneous conclusions. Thus, to circumvent these difficulties, the raincells were compared based on partitioning according to path lengths of ≤4, ≤8, or - 12 miles. This stratification allows the inspection of the data in absence of heavy cells with path lengths greater than 12 miles. Certainly, cells with shorter path lengths have a greater opportunity of being equally sampled in the areas shown on Fig. D-1. Results from the comparison of effect and non-effect cells stratified according to path length are listed in Table D-3.

For the ≤ 4-mile stratification, the magnitudes of the percentage increases for 1971-1973 are ranked according to areas in the same order as in all cells. That is, the SI cells had the largest percentage increases, the W cells had the second largest percentage increases, the L cells had the third largest percentage increases, etc. This helps to demonstrate that there is an effect present in the L, SI, W, and H stratifications which is not the result of sampling bias.

In the ≤ 12 miles category the magnitudes of the increases were ordered somewhat differently, but the percentage increases in the effect cells were still present, although the percentage increases were not as large as in the "all-cell" category. However, in the ≤ 12 miles category the percentage increase remained 177% in the SI cells and 128% in the L cells. *This indicates that the major portion of the increases in rainfall volume can be attributed to factors other than biased urban sampling of heavy and long moving cells.*

The mean volume of the control cells was only 10% greater for "all-cells" than for the cells - 12 miles. In comparison, the mean volumes for L, SI, W, and H cells were 32, 46, 67, and 31% greater, respectively, for all cells combined than for cells - 12 miles. Thus, the control cells did not sample as many of the heavy and long-moving cells (> 12 miles) as did the areas designated L, SI, W, and H. This may be due to the positioning of areas shown on Fig. D-l, or the control areas actually generated less of the longer-moving cells.

Inspection of Table D-3 also indicates that the tendency for heavy and long-moving cells to occur in W was the strongest in 1972. Further investigation was made of this tendency by accumulating the point totals of rainfall within the W cells during 1972 and the resulting cell pattern is depicted on Fig. D-4.

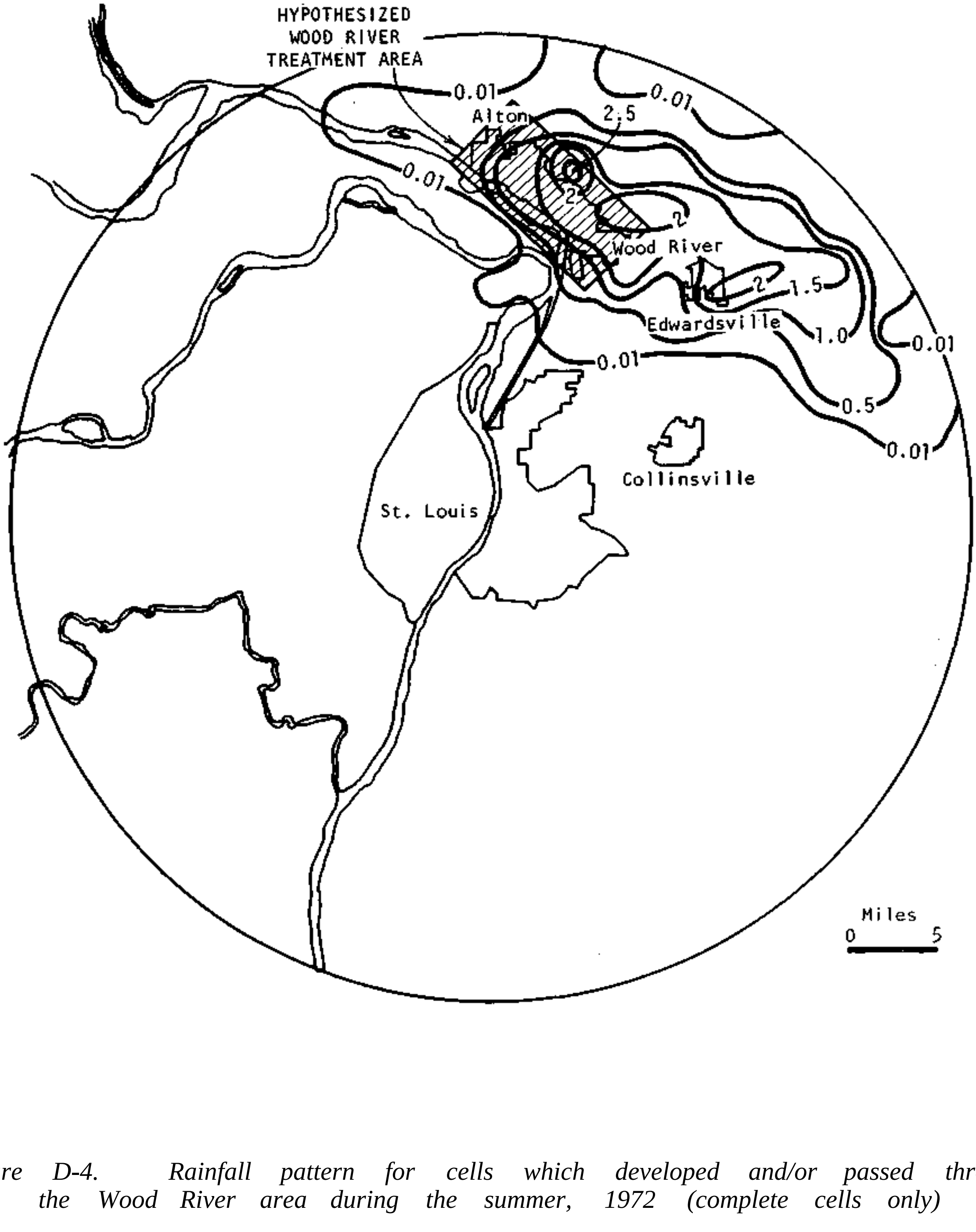

Figure D-4. Rainfall pattern for cells which developed and/or passed through the Wood River area during the summer, 1972 (complete cells only)

The cell pattern illustrates that long-moving cells in W occurred with cell movements from the northwest. This combination of movement and positioning produced a high center in the Edwardsville area which was caused by cells that developed and/or passed through the W area. Thus, W cells in 1972 had a movement pattern which deposited rainfall in the area of the Edwardsville high center (see Section C). The total pattern for W cells in 1973 (not shown) reveals that these cells only deposited a 1-inch high center in the Edwardsville area. This center was located on the west side on Edwardsville and closer to the Wood River area than in 1972. Similarly, the Edwardsville high was less intense in 1973 than in 1971-1972 (see Section C). This suggests that the percentage increases shown in Table D-3 in the W cells > 12 miles are not necessarily the result of bias but may be due to inadvertent modification processess induced by the presence of the cells in the W area.

Meteorological and Temporal Conditions Associated with the Urban-Induced Increases in Rain Production

The raincells were partitioned according to synoptic types used in Section B. This partitioning reduced the sample to a size such that only squall areas, squall lines, air mass, cold fronts, and static fronts had sufficient numbers of raincells to make comparisons between effect and non-effect cells. A comparison of cell volume from effect and non-effect cells according to synoptic type for the combined summers of 1971, 1972, and 1973 is presented in Table D-4. Some of the areas had small sample sizes (< 15) within the partitions of air mass, cold fronts, and static fronts and were eliminated from the comparison.

In the control sample, the squall-line and cold-front cells were the heaviest rain producers. In L, the largest percentage increases occurred with cells from static fronts and squall areas. The largest percentage increases in W occurred with cells from squall lines. In the SI cells, the largest percentage increases occurred with squall areas, but squall lines also had large percentage increases.

Because of possible sampling bias due to location of effect areas and/or positively skewed rainfall distributions, cells with path lengths longer than 12 miles were removed and the synoptic comparisons for cells ≤ 12 miles are shown in Table D-5. In the modified control sample, squall lines and cold fronts remained the heavy rain producers. In L and H, the largest percentage increases occurred with the squall-area cells with the second largest percentage increases associated with the squall-line cells. In W, the largest percentage increases occurred with squall-line cells. The most pronounced difference was the change in L from a 216% increase in static-front cells to a 97% increase.

Because of the problem of small sample sizes, it is difficult to derive firm conclusions except for air mass, cold front, and squall line categories. The following conclusions are made in regard to squall lines and squall areas: most of the cell rainfall occurs with squall areas and squall lines; the squall area cells have the largest percentage increases in L, SI, and H; and the squall line cells have the largest percentage increase in W, with no increase in squall area cells. This difference indicates that the physical processes acting on Wood River cells may be different from those acting on St. Louis cells. These differences might be due to differences in nuclei or differences in thermal structure.

Table D-4. Comparison of Average Rainfall Volume from Effect and Non-Effect Cells According to Synoptic Type for Summer 1971-1973

	Areas where Cells Developed and/or Passed					
	St. Louis (L)	St. Louis-Industrial (SI)	Wood River (W)	Hills (H)	Bottom-lands (B)	Control (C)
			Volume (Acre Ft)			
Squall Area	275(199)*	406(341)	95(3)	268(191)	100(9)	92
Squall Line	404(169)	538(259)	526(251)	270(80)	156(4)	150
Air Mass	96(8)	***	***	***	105(18)	89
Cold Front	279(87)	156(5)	***	***	202(36)	149
Static Front	256(216)	***	***	***	***	81
			Sample Size			
Squall Area	141	43	39	32	62	395
Squall Line	270	109	51	47	88	620
Air Mass	39	6	9	12	20	126
Cold Front	53	17	12	12	16	164
Static Front	24	12	8	8	6	82

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* Effect-control difference expressed as % of control in parentheses

*** Sample size too samll for comparison (< 15)

The diurnal distribution of cell rainfall for the summers of 1971, 1972, and 1973 was investigated by dividing the cells according to occurrence in four periods, 0001-06 00, 0601-1200, 1201-1800, and 1801-2400 DST. The purpose of this division was to determine if the four areas (L, W, H, and B), representing potentially different source agents, produced different effects during certain periods of the day. If so, this might provide indirect indications of the contribution of diurnal and urban heat inputs to the urban enhancement of rainfall. The mean volumes for each area are listed in Table D-6.

Table D-5. Comparison of Average Rainfall Volume from Effect and Non-Effect Cells According to Synoptic Type for Summer 1972-1973 and for Cells with Path Lengths ≤ 12 miles

	Areas where Cells Developed and/or Passed					
	St. Louis (L)	St. Louis-Industrial (SI)	Wood River (W)	Hills (H)	Bottom-lands (B)	Control (C)
			Volume (Acre Ft)			
Squall Area	236(157)*	325(253)	85(-8)	235(155)	100(9)	92
Squall Line	308(133)	363(175)	332(152)	221(67)	153(16)	132
Air Mass	87(36)	***	***	***	105(64)	64
Cold Front	207(57)	156(18)	***	***	202(53)	132
Static Front	144(97)	***	***	***	***	73
			Sample Size			
Squall Area	132	38	37	31	62	393
Squall Line	252	96	48	45	86	610
Air Mass	37	3	9	11	20	125
Cold Front	50	17	11	11	16	162
Static.Front	20	9	8	6	6	80

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* Effect-control difference expressed as % in parentheses

*** Sample size too small for comparison (< 15)

Table D-6. Comparison of Average Rainfall Volume from Effect and Non-Effect Cells According to Time of Day and for Summer 1971-1973 (Volume in Acre Ft)

	Areas where Cells Developed and/or Passed					
Time (DST)	St. Louis (L)	St. Louis-Industrial (SI)	Wood River (W)	Hills (H)	Bottom-lands (B)	Control (C)
0001-0600	155(112)*	198(171)	117(60)	70(-4)	58(-21)	73
0601-1200	156(73)	162(80)	251(168)	159(77)	103(14)	90
1201-1800	567(215)	824(358)	636(253)	412(129)	199(11)	180
1801-2400	258(134)	383(248)	275(150)	227(106)	142(29)	110

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* Effect-control difference expressed as % of control in parentheses

In every stratification, the heaviest rainfall occurred during the maximum heating period, 1201-1800, and the lightest rainfall occurred during the minimum temperature period, 0001-0600. The largest percentage increase occurred in the 1201-1800 period for W and H cells, and the smallest percentage increase occurred during the 0001-0600 period. For the L and SI cells, the largest percentage increase occurred in the 1201-1800 period but the smallest increase occurred in the 0601-1200 period. The percentage increases in L during the 0001-0600 and 1801-2400 periods were nearly the same. This is in contrast to the 1971-1972 results (Schickedanz, 1974) in which the percentage increase in the L cells was nearly the same in the early morning (0001-0600) period as in the afternoon (1201-1800) period. The percentage increase in Table D-6 is larger in L than in W in the early morning period which was also true in the 1971-1972 results, but the magnitude is less. Thus, whereas the 1971-1972 results suggested the presence of an increase in cell rainfall during the early morning hours when the urban heat island is well developed, the overall 1971-1973 results are only weakly indicative of such an increase.

The time stratification was also made for cells with path lengths less than 12 miles. There are two major differences between the results of this stratification and the results shown in Table D-6: 1) the large percentage increase in the W cells in the 1201-1800 period is reduced to a value of 111% while the corresponding percentage increase in the L cells is reduced to 185%, and 2) the percentage increase in L during 1201-1800 is approximately three times that of the other three periods, while the percentage increase in W during 1201-1800 is two times that of the 0001-0600 period and only 40% greater than that of the 1801-2400 period.

Thus, for the time stratification of cells with path lengths ≤ 12 miles, the percentage increase is greatest during the maximum heating period, and it is much greater than the corresponding increase for the W cells. Also, the early morning increase is much less in reference to the afternoon increase. These findings indicate that the L and W cells are increased the most when convective activity is the strongest., but that the increase in W is smaller. This indicates that heat may be a more important factor in L than in W for cells of path lengths ≤ 12 miles.

Analyses of Cell Initiation

A raincell analysis provides useful information concerning the areas in which cells tend to initiate. For example, it is useful to show whether cells tend to initiate more in the vicinity of urban sources of heat, moisture, and nuclei than in other regions. In addition, because of potential effects associated with hills and bottomlands upwind of the urban-industrial regions, mentioned previously, it is important to determine whether cells tend to initiate more in these areas also.

The number of times that each gage was included in a cell initiation during each summer month of 1971-1973 was tabulated and mapped. These tabulations were also mapped 1) for the 3-year totals for June, July, and

August 1971-1973, 2) for each of the three summers, and 3) for all nine months combined. The various maps were then subjected to trend surface analysis in the manner described by Schickedanz (1973b) to determine which initiation maxima were significant at the 1, 5, and 10% levels.

The initiation areas significant at the 1, 5, and 10% significance levels are shown on Figs. D-5, D-6, and D-7 for the three summer months (June, July and August) 1971-1973. The outer isoline represents the 10% significant level, the first inner isoline represents the 5% level, and the innermost isoline (if present) represents the 1% significance level. For June 1971-1973 there was a major initiation area in the vicinity south of the city which is also ENE of the hills. There were also significant initiation areas in the vicinity of Wood River, Edwardsville, Granite City, Lambert Field, and SW of Wood River. For July 1971-1973, there were two prominent initiation areas S and SE of the city. There were smaller initiation areas at Granite City, Wood River, SW of Lambert Field, at the bend in the river NE of St. Charles. For August 1971-1973, there were two initiation areas S and SE of the city, a very prominent initiation east of Lambert Field and small 10% areas in the city and at Collinsville.

The most persistent initiation area was S and SE of St. Louis. The Granite City and Wood River initiation areas were present in June and July, as was the initiation area near the bend of the River. The initiation area at Lambert Field was present in June and August, and the initiation area between Collinsville and Belleville was present in June and July. *The striking feature of the initiation maps is the absence of initiation areas in the city of St. Louis.*

The uniqueness of the nine individual monthly maps is best retained by making counts of the number of times that a gage was included in 5% and 10% significance levels on the monthly maps. The number of counts over the 3-year period are shown on Fig. D-8. The most prominent areas were 1) the maximum S of the city and E of the hills, which indicates that at the center of the maximum there was one gage included in a significant initiation area in 6 out of 9 months, and 2) the maximum at Granite City. Initiation areas of lesser prominence were located at the bend of the river, Lambert Field, east of the Wood River and in the Wood River-Edwardsville region.

Although the initiation area SE of the city is not in the city itself, it may still be due to industrial effluents from heavy industries in the southern part of St. Louis and in East St. Louis (Schickedanz, 1973b). However, this would require cumulus clouds to form over the industries and then move 4-6 miles SE prior to the occurrence of precipitation. Another possibility is that clouds aloft over the initiation area may merge with clouds which formed over the city, with the raincells first appearing in the initiation area. However, this rain initiation area is also ENE of the hills and a major portion of it lies on the bluffs (Schickedanz, 1973b). A factor which augers against the initiation maximum SE of the city being associated with the industries is that the other initiation areas are generally close to the sources of possible effluents. These are near sources of industrial effluents

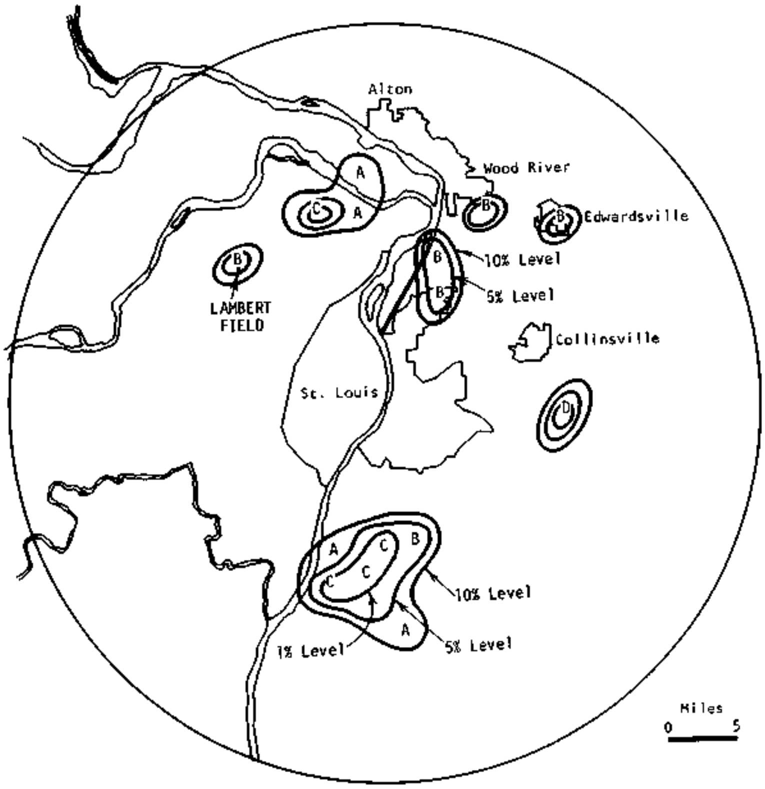

Figure D-5. Significant initiation areas as determined by trend surface analysis for June 1971-1973

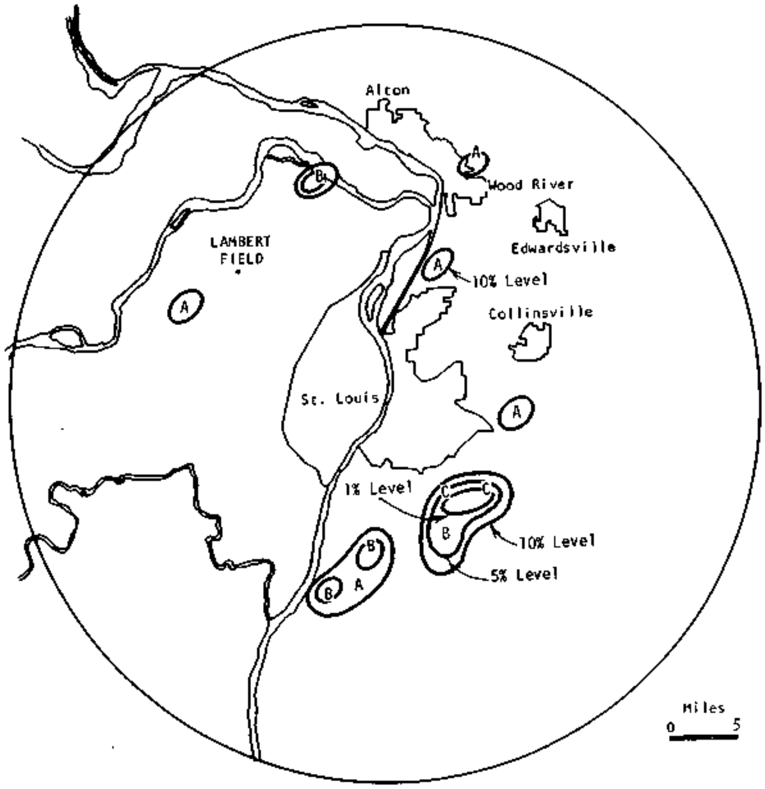

Figure D-6. Significant initiation areas as determined by trend surface analysis for July 1971-1973

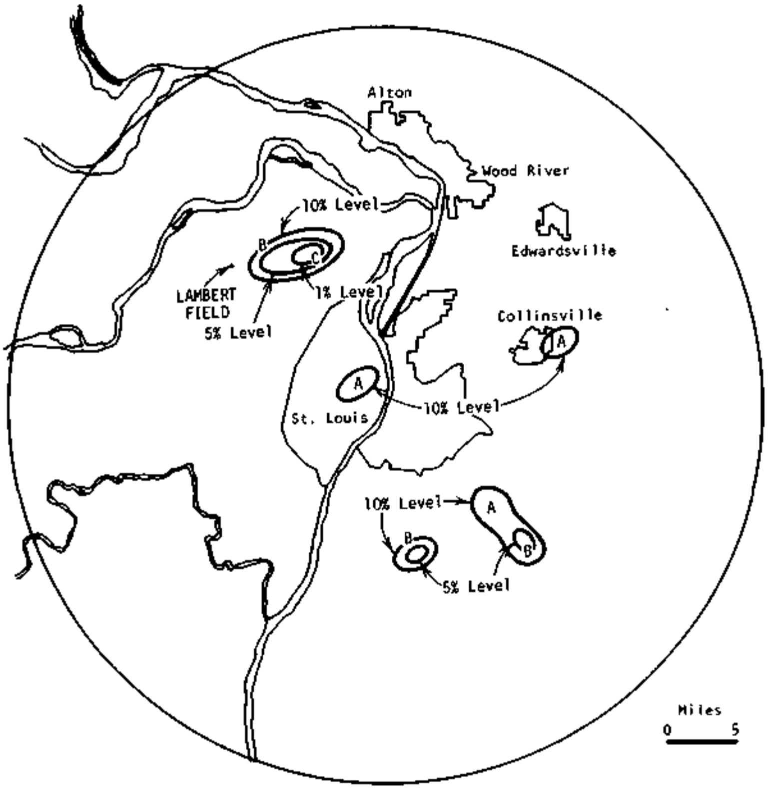

Figure D-7. Significant initiation areas as determined by trend surface analysis for August 1971-1973

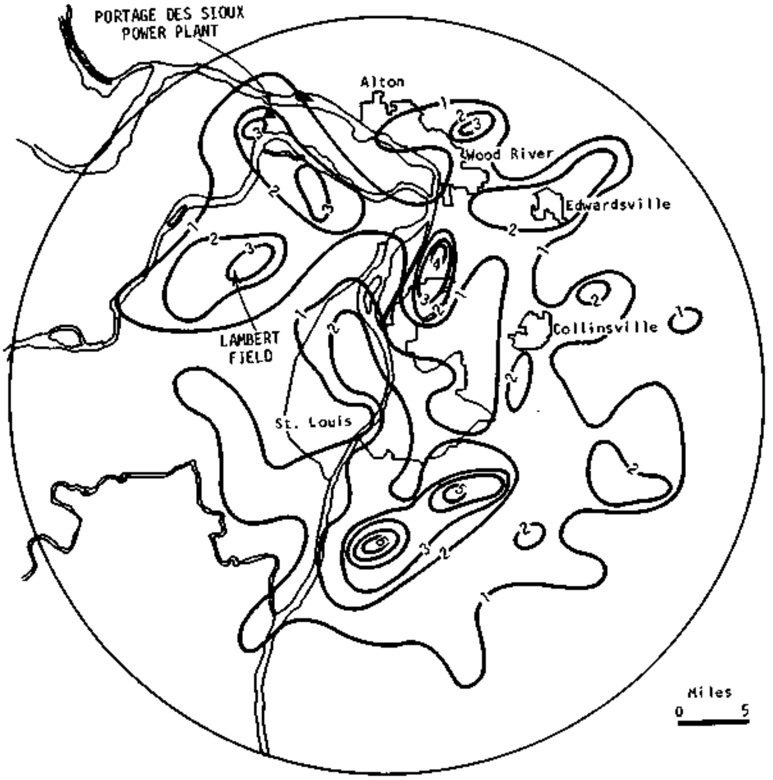

Figure D-8. Number of times each gage was included in a 10% significant initiation area on the monthly initiation maps for summers 1971-1973

(Wood River and Granite City), effluents from air traffic (Lambert Field) or power plants (Portage de Sioux). Discussion of cell initiation in reference to surface sources of heat and moisture is discussed in Section I.

Investigation of the initiation maps for the individual summers of 1971-1973 (not shown) revealed that 1) the Granite City and Wood River initiation area was present in 1971 and 1973, 2) the initiation area at the bend of the Missouri River was present in 1971, 3) the initiation area east of Lambert Field was present in 1972, and 4) the initiation area between Collinsville and Belleville was present in 1972 and 1973. The general initiation area S and SE of the city was present in all three summers.

Conclusions

The major conclusions derived from the 1971-1973 raincell analyses are listed below:

1) Cells that occurred in the urban-industrial areas produced the largest percentage increases in cell volume when compared with control cells (C). The percentage increase in volume was 172% for the urban-industrial region of St. Louis (L), 266% for the St. Louis industrial area (SI), and 179% for the industrial area of Wood River (W).

2) For cells occurring in the hill region SW of St. Louis, the volume increase was 91%, and for cells in the Bottomlands (B) the volume increase was 14%. Thus, the percentage increase in the L and W cells was approximately twice that of the H cells, and the percentage increase in the SI cells was approximately three times that of the H cells, while the increase in the Bottomlands was relatively small. The largest increase in the Hill cells occurred in 1973, which was the wettest year.

3) Cells in 1972 had the greatest volumes, the longest durations, and the largest areas, but not the largest means. With the exception of the W areas, the 1973 cells had the largest means but the smallest areas. Thus, the intensity of cell rainfall was the greatest during the Summer of 1973 (i.e., large mean rainfall over small areas) and this was the wettest summer.

4) For the L and SI cells, the percentage increase in mean rainfall increased as the summers became progressively wetter. This trend was not present in the Wood River cells, and suggests a different underlying physical relationship. This might be attributed to different kinds of nuclei in St. Louis as compared to Wood River, or to differences in thermal structure.

5) For cells with path lengths less than 12 miles, it was found that the percent increase was 128% in L cells, 177% in SI cells, 84% in W cells, 61% in H cells and 24% in B cells. This clearly indicates that the major portion of the increases in rainfall volumes can be attributed to factors other than bias sampling of heavy and long-moving cells.

6) Most of the percentage increase in W cells resulted from a few long and heavy raincells. The W cells in 1972 had a movement pattern which deposited rainfall in the area of the Edwardsville high.

7) Most of the 1971-1973 cell rainfall occurred with squall areas and squall lines. The squall area cells showed the largest percentage increase in L, SI, and H. The squall line cells were associated with the largest percentage increase in W, and there was no increase with squall area cells. These differences indicated that the physical processes acting in Wood River may be different from those acting in St. Louis cells. Again, differences might be due to differences in nuclei or differences in thermal structure.

8) In all stratifications, the heaviest rainfall occurred during the maximum heating period, 1201-1800 and the lightest rainfall during the minimum heating period, 0001-0600. Results from 1971-1972 suggested a percentage increase in cell rainfall during the early morning hours when the heat island is well developed. However, the overall 1971-1973 results are only weakly indicative of such an increase.

9) An investigation of raincells with path lengths less than 12 miles indicated that the L and W cells were increased the most when convective activity was the strongest, and that the increase in L was stronger than in W.

10) The most frequent initiation area was south and east of the St. Louis urban-industrial area, but another pronounced initiation area was located at Granite City. Initiation areas of lesser prominence were located at the bend in the Missouri River near Portage de Sioux, at Lambert Field, east of Wood River, and in the Wood River-Edwardsville region.

11) A striking feature of the initiation maps is the lack of significant initiation areas in the city of St. Louis. Most initiation areas are located close to the industrial sources of effluents with the exception of the prominent initiation area southeast of the industrial area of East St. Louis. The initiation area southeast of the city may be due to the formation of cumulus clouds over the industries which then move 4—6 miles prior to the occurrence of precipitation. However, the initiation area is also ENE of the hills and a major portion of it lies on the bluffs. A factor which augers against the initiation being associated with industries is that the other initiation areas are closer to the sources of possible effluents.

Overall, the 1971-1973 results provide strong evidence that the urban and industrial environment has altered the precipitation regime. Increases in rainfall volume of cells with relatively short path lengths clearly indicate that increases in rainfall volume are not simply the result of bias or chance sampling of long and heavy cells.

The precise causes of the precipitation increase are still unknown. It was found that the highest percentage increase in cell volume occurred in a heavy industrialized region within the city of St. Louis, which is a known source of Aitken nuclei. This suggests that micro-physical processes are an important factor in the rainfall increase. However, characteristics of cells in another highly industrialized area (Wood River) are somewhat different than characteristics of cells in the industrial area of St. Louis. Furthermore, the St. Louis industrial area is also located in the vicinity of surface heat and moisture sources (see Section I) and this indicates that dynamic influences are also important. Thus, it is likely that both micro-physical and dynamic effects are involved in the precipitation increase at St. Louis. Additional studies of the raincell data in relation to warm and moist surface conditions are underway, and it is hopeful that these studies will provide additional insight into the effects of heat and moisture.

The 1971-1973 analyses suggest that additional research should be performed in several areas. These areas are as follows: 1) analyze one year of data using a different definition of the raincell which includes a greater percentage of the overall storm rainfall, and which uses a constant base isohyet, 2) analyze a class of cells which initiate in urban and industrial areas, as opposed to those which initiate in control areas, and 3) additional analyses of the total raincell patterns.

Acknowledgment

Appreciation is expressed to Marion Busch who performed the computer analyses and supervised various other critical analyses.

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E. ANALYSES OF PPI RADAR ECHO DISTRIBUTIONS

F. A. Huff and E. E. Schlessman, Jr.

Introduction

Processed radar echo data for the FPS-18 (10-cm) radar have been analyzed for 17 storm periods during the summers of 1972-1973. The sample consists of 8 storms in August 1972 and 9 storms in July and August 1973. The 1972 sample was limited to August storms because of operational and maintenance problems with the FPS-18 integrator system. The 1973 data processed to date are those for special cases studies described in another NSF report under preparation by the Water Survey Staff. Additional 1973 data will eventually be processed to increase the sample size, but the necessity of using NCAR facilities for the computer analysis required in the radar studies, along with certain operational and analytical priorities, have delayed completion of the task. The FPS-18, its integrator system, and basic data processing methods have been described by Brunkow and Morgan (1973).

This section of the interim report will be concerned with analytical results of the 17-storm study. The spatial distribution of initiation of radar echoes will be described with primary emphasis on comparisons of urban and non-urban conditions. Mergers of radar echo systems, which frequently precede intensification of surface rainfall, will be discussed and assessed with respect to urban and non-urban effects on these mergers. A statistical summary of the movement, duration, and various other definitive parameters of the echo characteristics will be presented, with stratifications according to urban, non-urban, and topographic exposures in their development and/or movement.

The FPS-18 was operated with minimum detection levels of 27 dbm in 1972, 32 dbm in July 1973, and 42 dbm in August 1973. This inconsistency has limited the direct comparison of analytical results to some extent, but much useful information relative to the urban rainfall effect was obtained from the radar echo records. The 2° beam antenna had a fixed elevation of 0.5°, thus essentially sampling near surface precipitation.

In the various analyses, it was decided to employ a grid system of 3 x 3 statute miles or unit areas of 9 mi^2, which are approximately equivalent to the area represented by each raingage in the METROMEX Network. The FPS-18 was located at the Pere Marquette Headquarters (PMQ) which was too close to the extreme NW portion of the raingage network for reliable echo analysis. Consequently, a 16-mile radius from PMQ was designated the "radar noise blackout area: and was not used in any of the echo studies. This eliminated 30 of the grid squares (270 mi^2) in the NW part of the research circle of 26-mile radius (approximately 2100 mi^2). In some analyses, four of these grid squares were combined to provide averages over 36 mi^2 because of relatively small sample sizes in the 9-mi^2 squares.

Radar Echo Initiations

Initially, all echo intensity centers (reflectivity centers) for each minimum dbm level were examined separately by plotting the locations on the grid base map. An echo intensity center was defined as a closed center (gain step) of maximum reflectivity associated with a radar echo system. The system could contain one or several intensity centers. In a multicellular echo system, each separate intensity center was counted in tabulating the echo initiations. For each storm group (27, 32, and 42 dbm), a rainfall map was also constructed for the period in which the echoes were recorded on the integrator. Because of the size of the sample, this analysis was based upon the 36-mi^2 grid rather than the 9-mi^2 network. The radar echo initiation counts for each dbm-level are shown in Figs. E-1, E-2, and E-3. In all three storm groups, one of the most frequent areas of echo initiation was south of Wood River in the vicinity of a group of oil refineries (grid square EF-11, 12). Two other areas of consistently high initiations were located in South St. Louis (grid square IJ-9, 10), and in the SE part of the Urban area (IJ-11, 12). Overall, there was a relatively high frequency of initiations consistently in the urban-industrial areas of St. Louis and Wood River and E and NE of St. Louis in the Edwardsville-Collinsville-Belleville region where downwind effects would most frequently occur because of the pronounced trend for storms to move across the METROMEX Network with a westerly component (SW-W-NW). Minor shifting occurred among the three groups of outstandingly high initiations from one grid square to another in this general region in and east of the urban-industrial regions. This is most likely associated with variations in dominant synoptic weather features between the three sampling periods, particularly the movement of convective elements. This factor will be investigated further.

Next, it was decided to combine the data for the two summers despite variations in the minimum detection level. This provided a much larger sample which permitted more precise definition of initiation areas through use of the 9-mi^2 grid. Despite the change of dbm level with time, all parts of the network were exposed to the same situation, so that the total 2-summer pattern should provide a satisfactory first estimate of the echo initiation distribution on the METROMEX Network.

Figure E-4 shows the total occurrences of echo initiations in the 2-summer, 17-storm sample. A total of 25 initiations in the grid square just south of Wood River was outstanding within the network. The oil refineries mentioned above are located in this grid square. This suggests that a development and/or convective cloud intensification center is associated with this potential nuclei source. Other outstanding areas of high frequency were located in and east of St. Louis. The mean grid square frequency for the 17 storms was 2.8, so that the 25 occurrences near Wood River was 9 times the network mean. The values in South St. Louis (15, 16) were over five times the network mean. These statistics further emphasize the pronounced preference for initiation that occurred in certain locations in potential urban-effect regions. A total of 257 grid squares were used in calculating the network mean. Over 50% of the network had two or less initiations, and less than 5% had 10 or more occurrences. All of this upper 5% occurred within the area of potential urban effects.

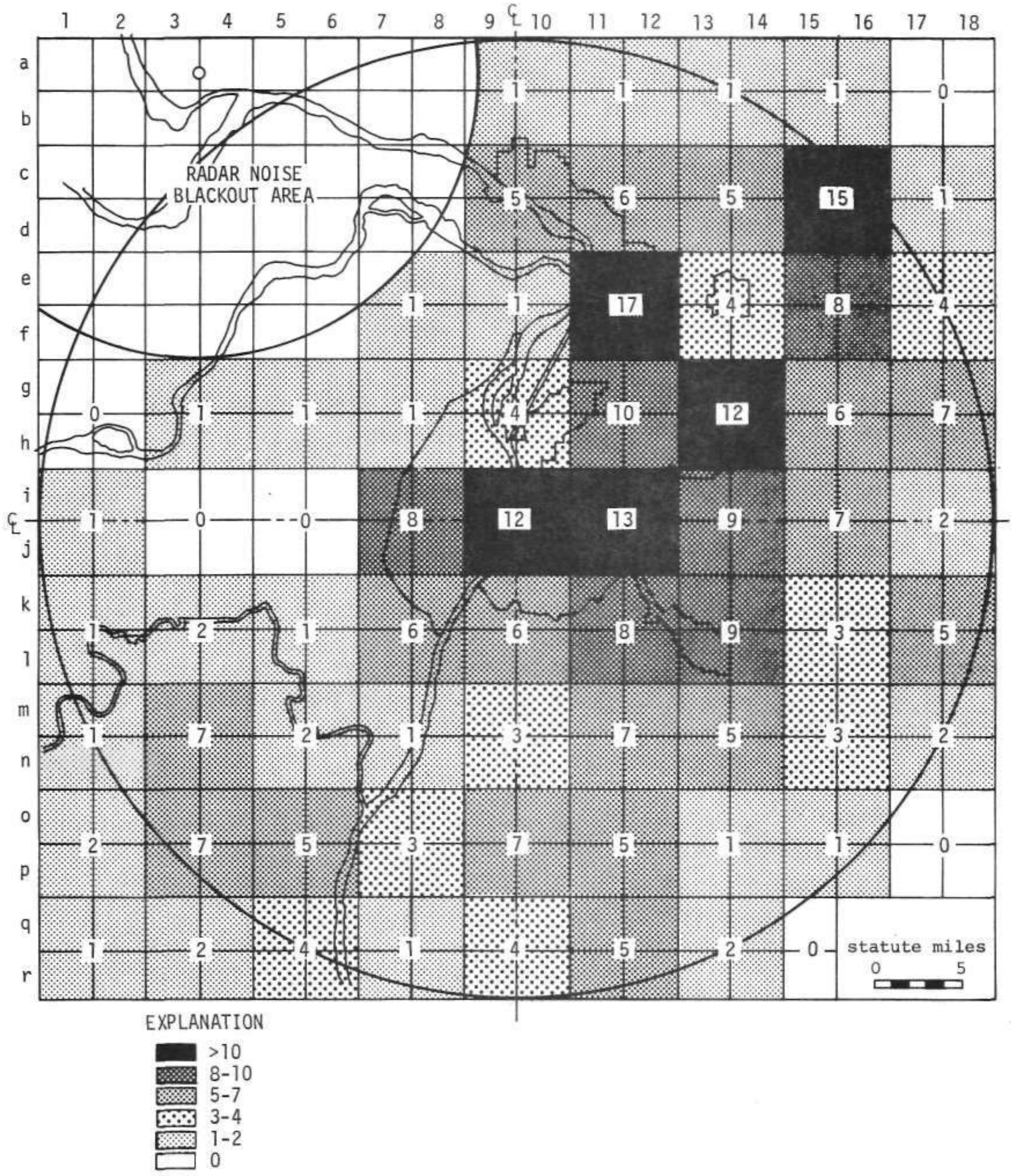

Figure E-1. Echo initiations at 27-dbm level in 1972

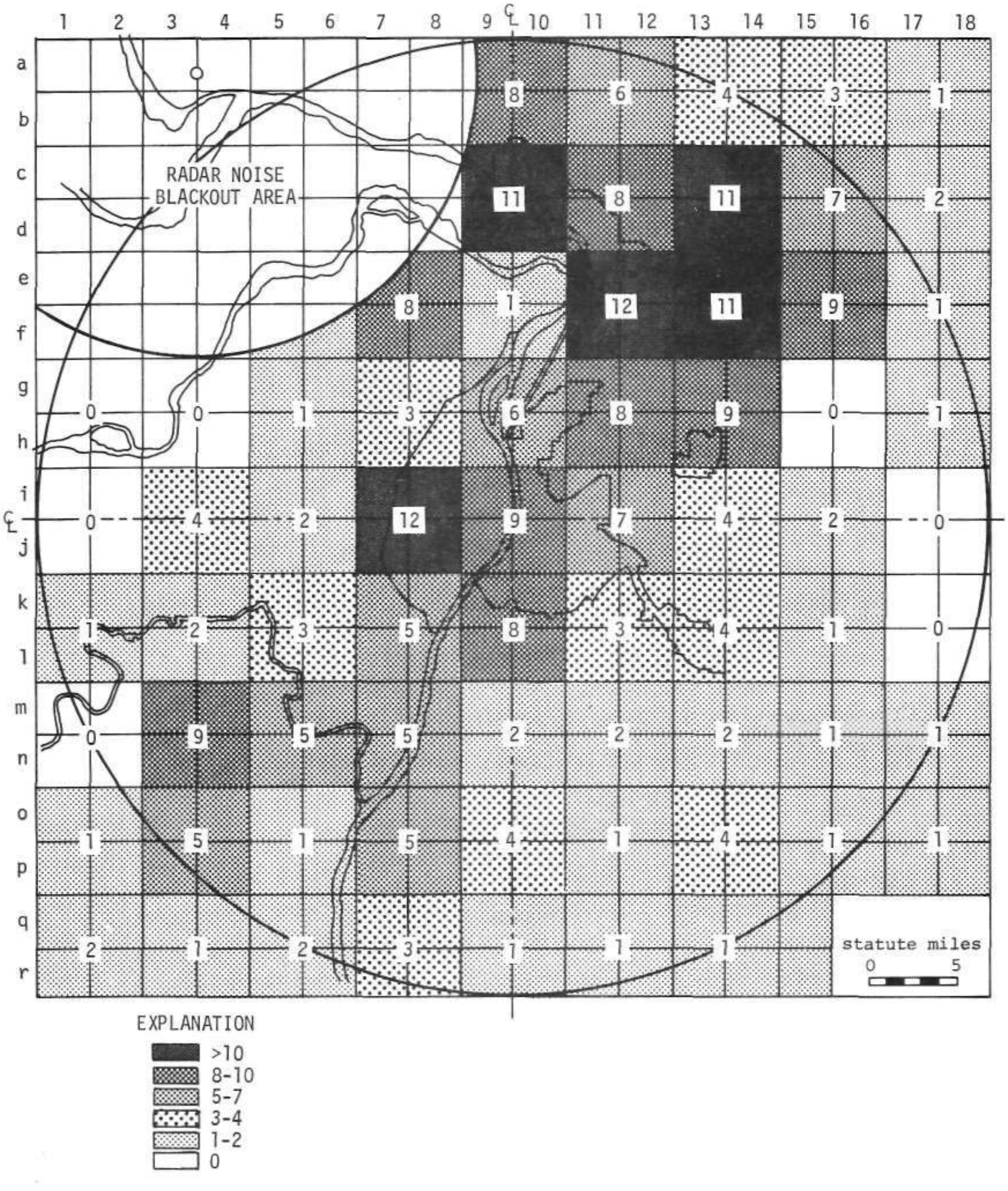

Figure E-2. Echo initiations at 32-dbm level in 1973

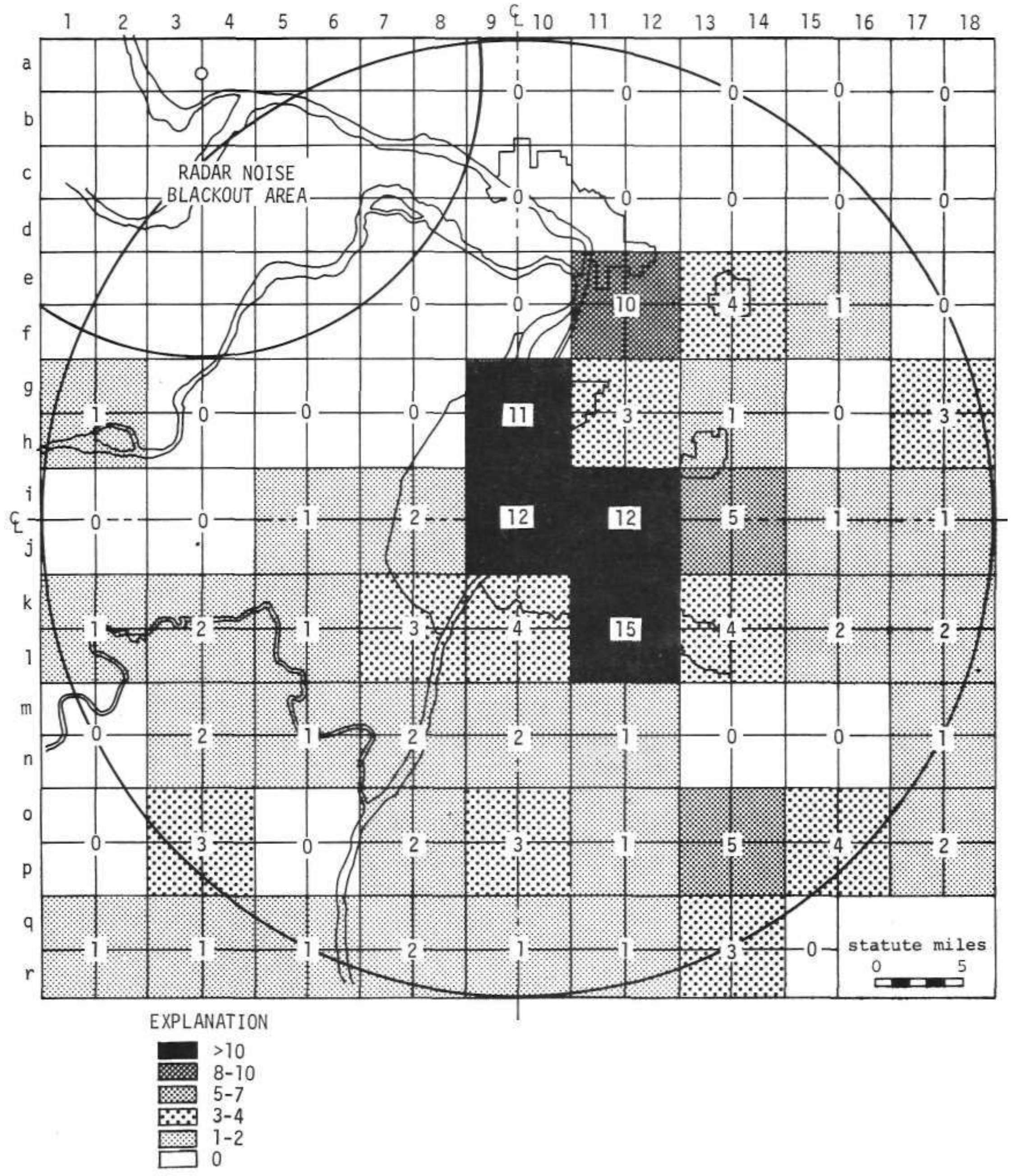

Figure E-3. Echo initiations at 42-dbm level in 1973

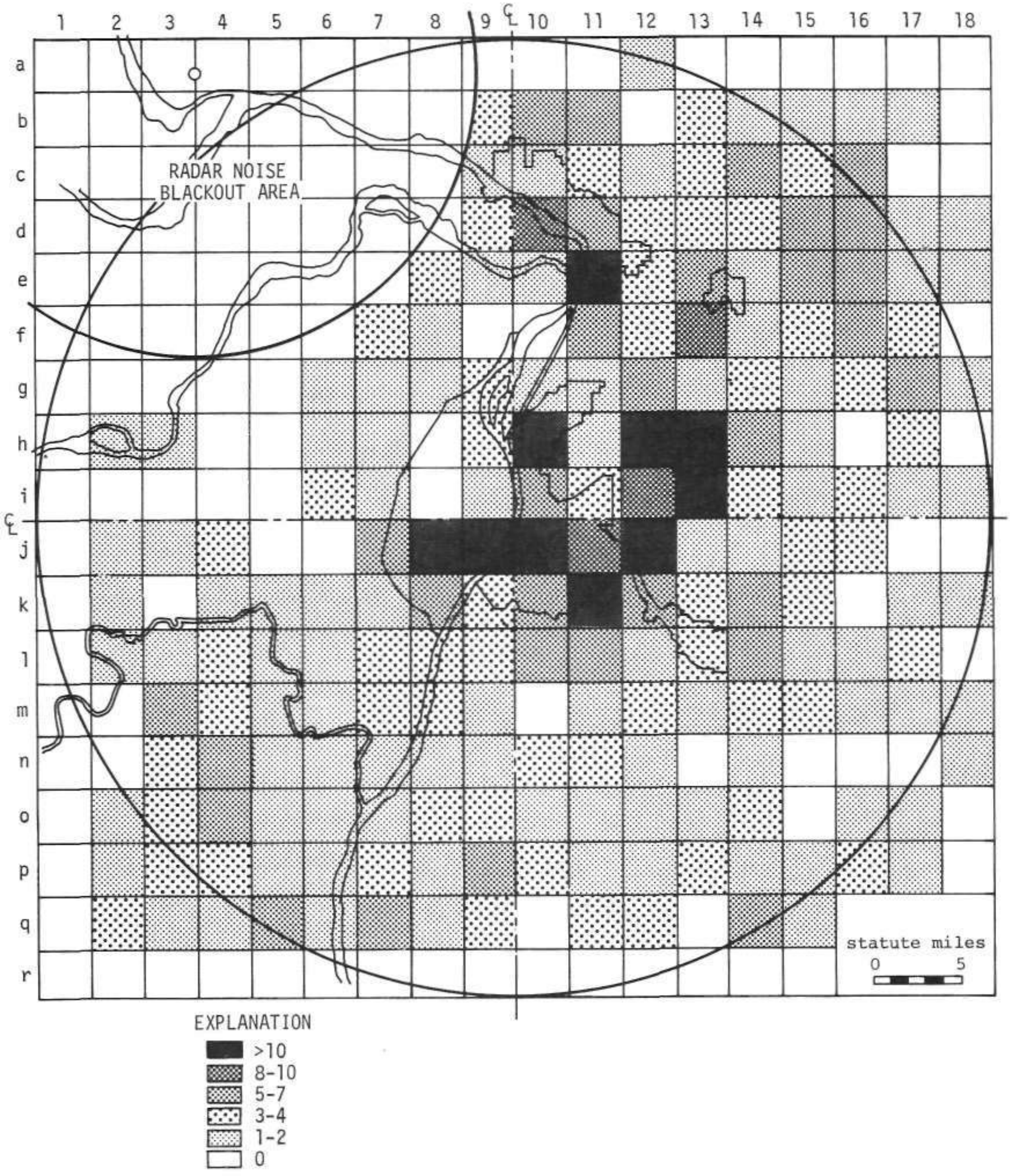

Figure E-4. Total number of echo initiations in 17 storms during 1972-1973

Assuming the distribution in Fig. E-4 is a reasonable approximation of the average distribution, one would conclude that raincells are most likely to develop and/or intensify south of Wood River, across the south central and southeast urban area of St. Louis, in the vicinity of the Granite City Steel Plant (11 occurrences in Fig. E-4), and in the vicinity of Collinsville and Edwardsville. However, in view of the relatively short 3-month, 17-storm total, it would be premature to reach this conclusion.

Figure E-5 shows the total rainfall occurring during the period in which radar echoes were recorded in the 17-storm sample. Only fair correspondence is indicated between Figs. E-4 and E-5. Thus, high echo frequencies and heavy rainfall amounts did closely coincide in the eastern part of St. Louis and in the Collinsville area, but the association was poor in the region of maximum echo occurrence near Wood River and W and SW of Edwardsville.

In the next step, a simple normalization procedure was used to minimize the rainfall effect on the echo frequency pattern. In doing this, an average rainfall (R) was determined for each grid square. Then, the number of initiation occurrences (I) in each grid square was divided by the mean rainfall to provide a value showing the number of echo initiations per inch of rainfall. This normalized pattern is shown in Fig. E-6.

Figure E-6 shows the echo initiation maximum located in the oil refinery grid, south of Wood River, to be most outstanding as it was in Fig. E-4. The mean ratio of I/R was 0.66 and the median was 0.51. Thus, the normalized maximum of 4.81 in the Wood River area was 7 times the average, compared with 9 times for the actual initiation counts in Fig. E-4. The normalized pattern, similar to Fig. E-4, shows outstanding maxima in South St. Louis.

However, some significant changes did result from the normalization process. The normalized pattern shows outstanding high frequencies in the SW part of the network in the Ozark foothills. In fact, the second highest value on the network (3.16) was in this region and 6 of the 10 highest ratios were located in this region. This indicates that the Ozark foothills are a favorable region for the development and/or intensification of convective activity, and consequently, raincells. Since these hills are recognized as a region where convective activity is likely to be stimulated, the finding is not surprising. In fact, it is reassuring, since it provides evidence that our 17-storm sample may be reasonably representative of average conditions.

The radar echo initiation study needs to continue and incorporate much more data to define more accurately the echo initiation pattern in the research area. However, these preliminary results are in general agreement with other analyses to date; that is, the echo initiation results indicate an urban effect on the development and/or intensification of convective storms. Furthermore, it has provided and will continue to provide information to aid in more accurately defining the location and source of the more pronounced urban effects. The indication of a pronounced maximum south of Wood River in the potential effect region of the oil refineries is especially interesting, and indicates a need for special attention to this region during the remainder

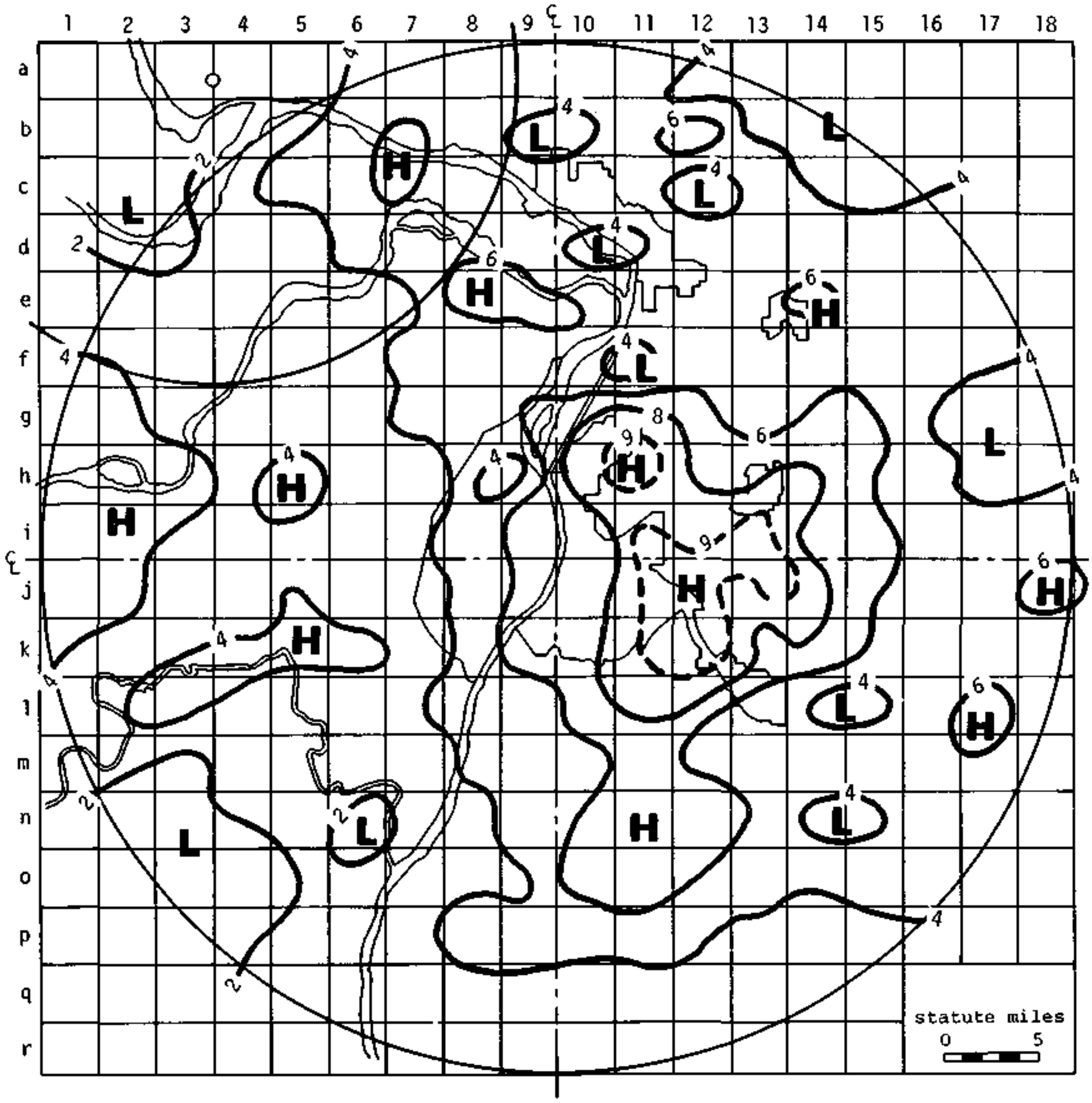

Figure E-5. Total rainfall (inches) associated with 17-storm sample of radar echoes in 1972-1973

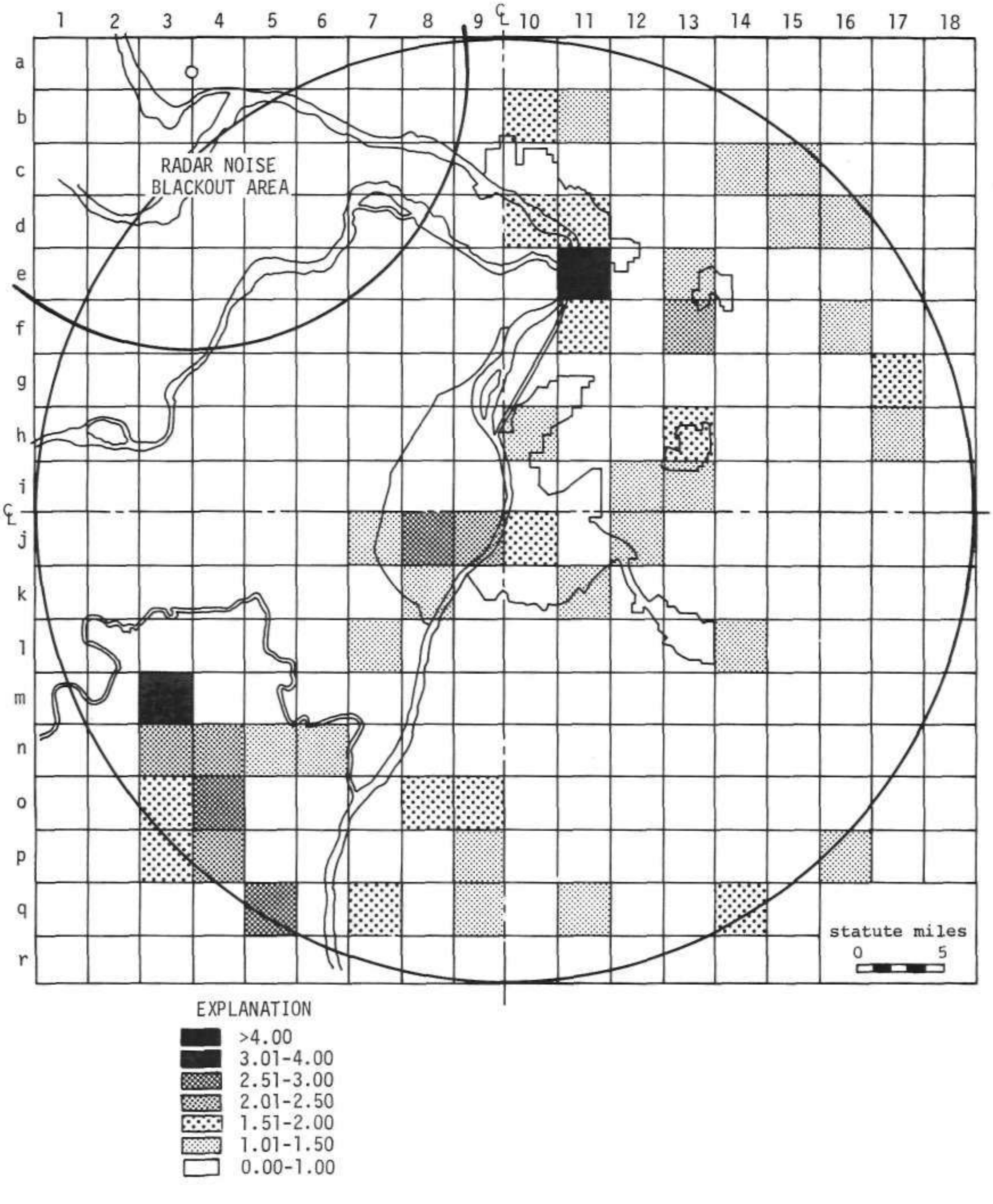

Figure E-6. Number of echo initiations per inch of rainfall in 17 storms during 1972-1973 of the METROMEX program. The south part of St. Louis also needs close examination on the basis of the patterns displayed in Figs. E-4 and E-6.

Radar Echo Mergers

Since mergers of convective clouds and rain systems have been shown to be associated frequently with rain intensification (Huff, 1967; Simpson et al., 1972), the 17-storm sample was used to investigate echo mergers. This was done only for distinct echo systems. A radar echo system was defined as an echo entity separated in space from other echoes, and the system may consist of one or several intensity centers within its enveloping isoecho. This is analogous to the raincell definition being used in our METROMEX studies.

A total of 53 mergers was identified in the 17-storm sample for August 1972 and July-August 1973. These were summarized and plotted on a 36-mi^2 grid on the METROMEX Network (Fig. E-7). Because of the relatively small sample size, results cannot be considered conclusive. However, evidence that mergers may be favored in urban areas was found.

Thus, the grid square with the most occurrences (5) was centered at the eastern edge of St. Louis and SW of Collinsville. Four mergers were identified in the SE part of the St. Louis urban area, and this grid was immediately south of the maximum of 5 occurrences. The network average per grid square was only 0.8 and the median was 0.0. Approximately 40% of the mergers were within the region bounded by St. Louis, Belleville, and Collinsville. Over 70% of the mergers were in the network area extending eastward and northeastward from St. Louis and Alton-Wood River. This is the portion of the network that is most frequently within the potential urban-effect region.

Comparison of Average Properties of Urban and Non-Urban Echo Intensity Centers

The sample of FPS-18 echo intensity centers from the 17 selected storms of 1972-1973 was analyzed for several climatological-statistical properties that could be readily obtained from the data. Analyses were made of the echo center duration, maximum intensity (dbz), path length, speed, and direction of movement. The echo intensity centers were stratified into the following groups: urban-effect cells with subdivision according to St. Louis (STL) and Alton-Wood River (ALT-WR) effect cells, potential urban-effect cells, no-effect or control cells, and hill-effect cells. There was an inadequate sample of bottomlands cells to separate in the analyses. Combinations of hill-urban and bottomlands-urban were also eliminated from the analyses because of very few occurrences.

An urban-effect cell was defined as an echo intensity center that developed within the urban-industrial area or passed over this area during its lifetime. A potential urban-effect cell was defined as one first detected 1) within 5 miles downwind of St. Louis or Alton-Wood River, or 2) within 20 minutes travel time from either of the urban-industrial areas, based upon the existing winds.

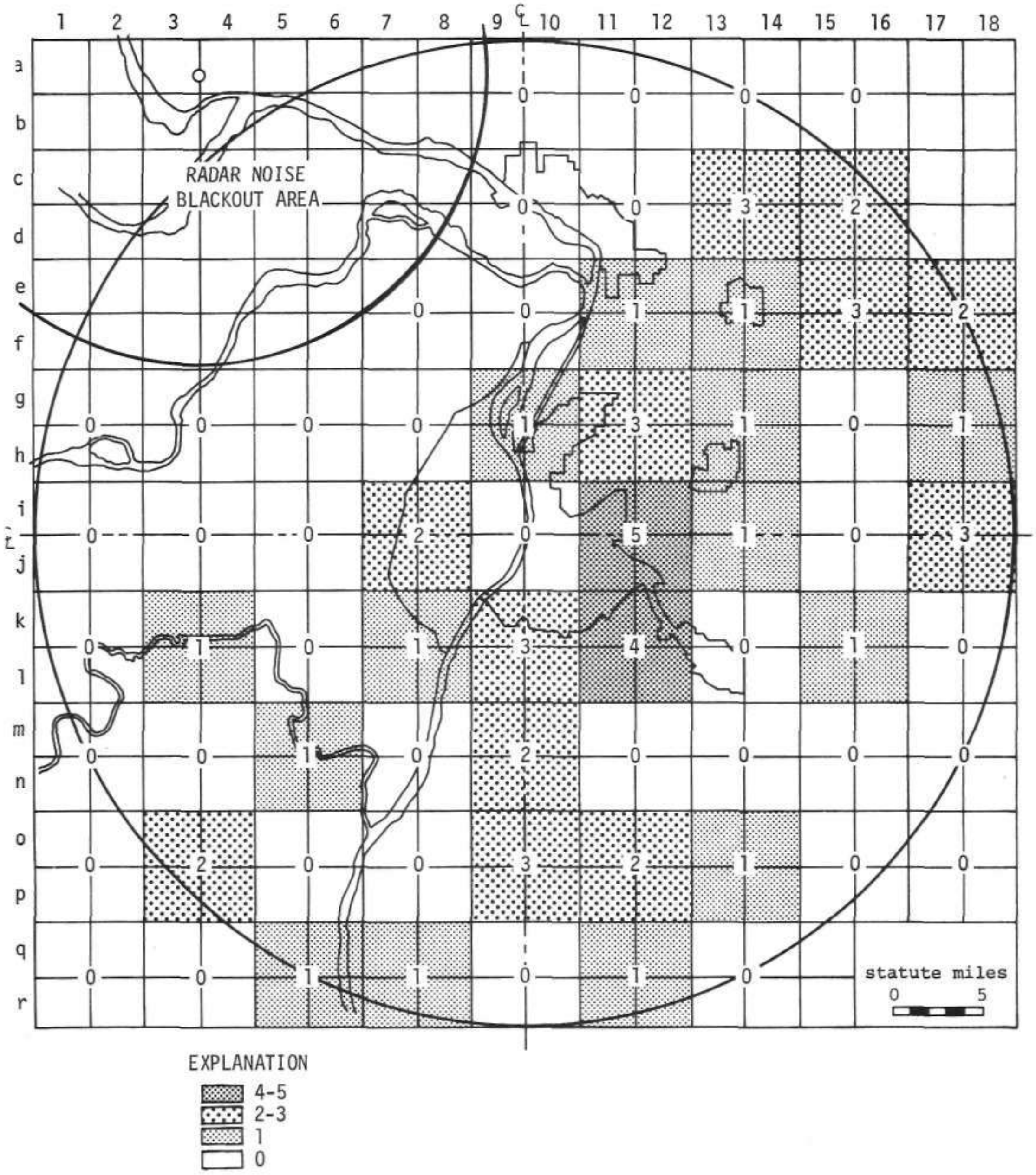

Figure E~7. Number of echo mergers in 17 storms during 1972-1973

Table E-1 provides a summary of the mean values for moving and quasi-stationary cells for each of the echo-type stratifications. Duration, path length, and maximum intensity provide a measure of the size and intensity of the echo intensity centers. The limited 1972-1973 sample indicates that the hill-effect storms were slightly larger and more intense, since all three of the above parameters were greatest with this group.

Moving cell comparisons of all urban-effect and no-effect echoes combined (STL, ATL-WR) show the urban intensity centers having considerable longer durations (+27%), path lengths (+30%), and maximum intensity (+14%). Thus, Table E-l provides additional support for an urban enhancement effect. No significant difference was noted in the mean speed of the urban and non-urban echo centers (Table E-l). The most frequent direction of motion of the urban cells was from 261-280 degrees compared with 241-260 degrees for the no-effect cells (Table E-2). However, the second most frequent direction for the no-effect cells was 261-280 degrees which included 14% of the total number of moving cells. In general, the most frequent direction was from 261-280 degrees, and combining all moving cells the percentage of the total was 23% from this direction (Table E-2).

Table E-l. Statistical Summary of FPS-18 Echo Cell Properties

Echo Type	N	Duration (Minutes)	Maximum Intensity (dbz)	Path Length (Miles)	Speed (mph)
	Moving Cell Means				
All Urban Effect	123	19	42	5.6	18-
STL Effect	96	19	43	5.7	18
ALT-WR Effect	27	19	41	5.1	16
All Potential Urban Effect	101	15	39	5.0	21
STL Potential Effect	79	15	38	4.8	20
ALT-WR Potential Effect	22	15	41	5.8	24
No Effect	178	15	37	4.3	18
Hill Effect	66	20	43	6.9	19
	Quasi-Stationary Cell Means				
All Urban Effect	43	22	41	-	-
STL Effect	19	26	41	-	-
ALT-WR Effect	24	20	41	-	-
All Potential Urban Effect	9	13	35	-	-
No Effect	13	11	38	-	-
Hill Effect	4	15	34	-	-

Table E-2. Movement of FPS-18 Echoes

Echo Type	N	Most Frequent Direction (deg.)	Percent of Moving Cells
All Urban Effect	123	261-280	27
STL Effect	96	261-280	29
ALT-WR Effect	27	281-300	26
All Potential Urban Effect	101	261-280	22
STL Potential Urban Effect	79	261-280	22
ALT-WR Potential Urban Effect	22	281-300	28
No Effect	178	241-260	17
Hill Effect	66	261-280	32
All Moving Cells Combined	468	261-280	23

Table E-3. Frequency of Quasi-Stationary Echo Intensity Centers

Echo Type	Number of Quasi-Stationary	Percent of All Echoes
All Urban Effect	43	26
STL Effect	19	17
ALT-WR Effect	24	47
All Potential Urban Effect	9	8
No Effect	13	7
Hill Effect	4	6

The means of duration, path length, and maximum intensity for the moving cells in the potential urban-effect class in Table E-1 were between the urban-effect and no-effect values. Although the sample is too small to reach valid conclusions at this time, the above statistics for 1972-1973 suggest that these echo intensity centers detected downwind of the urban-industrial areas may have experienced enhancement, but of a lesser degree than those cells developing directly over the urban-industrial areas. The hill-effect statistics suggest that the topographic effects of the Ozark Hills may have a stronger enhancement effect than the urban areas. However, in view of the small sample size, such a conclusion is inappropriate at this time.

The analyses of quasi-stationary echo intensity centers in Tables E-1 and E-3 provide some interesting statistics and implications concerning the urban effect. Except in the urban areas, quasi-stationary cells occurred in only a small percentage of the cases. Table E-3 shows that 26% of all the urban-effect cells were of the quasi-stationary type, compared with only 8, 7, and 6%, respectively with the potential urban-effect, no-effect, and hill-effect echoes. Further examination shows that the major cause of the relatively high urban percentage was the ALT-WR region, where the quasi-stationary echo centers accounted for 47% of the 51 centers included in the 17-storm sample.

As shown in an earlier discussion of echo center initiations, the most frequent region of initiation in the 17-storm sample was in the ALT-WR area in the vicinity of a group of oil refineries. Observations of METROMEX personnel and certain case studies have indicated the development of convective clouds and rainfall over this area with little or no movement of the convective entity. It is hypothesized that the lack of apparent movement may often result from the dissipation of the urban-generated system as it moves away from its generation source. A good example of this was in the early stages of a very heavy storm during the evening of 25 July 1973 when radar echoes appeared to be quasi-stationary in the above region for approximately 90 minutes before moving northeastward and intensifying. Verification of the quasi-stationary anomaly in the ALT-WR area and determination of its causes will require the collection of additional radar data and more detailed analysis of existing data.

Frequency Distribution of Urban and Non-Urban Echo Properties

Frequency distribution curves were derived for the duration, path length, maximum intensity, and speed of the echo intensity centers identified with the 17-storm sample. This was done to determine whether differences between urban-effect, potential urban-effect, hill-effect, and no-effect echoes varied significantly as the magnitude fo the echo parameters changed. Results are summarized in Tables E-4 to E-7 in which the parameter values have been listed for each echo-type stratification with decreasing magnitude; that is, these tables were constructed from the frequency distribution curves proceeding from the largest to the smallest values. For example, the 10% value in Table E-4 corresponds to maximum intensities that were equalled or exceeded in only 10% of the cases. Only moving cells were used in determining the frequency distributions. The size of the quasi-stationary samples was inadequate to compare frequency distributions. In general, the medians in Tables E-4 to E-7 are smaller than the means of Table E-l. This is due primarily to the skewness of the parameter distributions. Also, the frequency values were taken from smoothed curves drawn through a series of points. The differences are not unexpected in view of the large parameter variability and the sample sizes available for the analyses.

Table E-4 shows the distribution of maximum echo intensity for each type. A difference of 4–6 dbz is indicated between the urban-effect and no-effect or control cells at most of the percentage intervals. This consistent difference provides evidence of a general urban intensification of radar echoes which develop and/or move across the immediate urban areas of STL and ALT-WR. However, reference to the potential urban-effect tabulations in Table E-4 indicates only small differences between these and the no-effect echoes. Thus, there is only weak evidence of an urban-related intensifying of the echo intensity centers initially detected downwind of the urban areas. However, we are dealing only with maximum observed intensities here, and the possibility exists that the mean echo intensity is increased to a greater degree in these echoes.

Table E-4. Comparison of Maximum Intensity Between Echo Intensity Centers from Frequency Distribution Curves

	Intensity (debz) Equalled or Exceeded for Given Echo Type			
Cumulative Percent of Echoes	Urban Effect	Potential Urban Effect	No Effect	Hill Effect
10	53	47	47	52
20	47	43	43	48
30	45	41	40	45
40	42	39	37	43
50	40	37	35	40
60	38	34	33	38
70	36	32	31	36
80	33	29	28	34
90	30	26	24	31

The hill-effect echoes in Table E-4 show values nearly equal to the urban-effect echoes throughout the distribution. This implies that the topographic enhancement capability of the Ozark Hills and urban-effect areas are approximately equivalent, at least with regard to maximum echo intensities, and, therefore, maximum rainfall rates at the center of these convective entities.

A comparison of the frequency distributions of maximum intensities for moving and quasi-stationary cells among the urban-effect intensity centers was made. Results indicated a consistent 2-dbz greater intensity with moving cells along the entire frequency curve. This provides some evidence that the moving cells tend to produce slightly heavier rainfall rates during their period of peak output over or downwind of the urban area.

Table E-5. Comparison of Duration Between Echo Intensity Centers from Frequency Distribution Curves

	Duration (minutes) Equalled or Exceeded for Given Echo Type			
Cumulative Percent of Echoes	Urban Effect	Potential Urban Effect	No Effect	Hill Effect
10	43	28	30	38
20	28	21	21	29
30	20	17	16	23
40	16	14	13	20
50	13	12	10	16
60	11	9	8	13
70	9	8	7	11
80	7	6	5	8
90	5	5	5	6

The comparative frequency distributions for echo cell durations are summarized in Table E-5. The urban-effect cells exhibit longer durations than the no-effect cells throughout most of the frequency distribution, and the difference is most pronounced in the longer duration storm cells. The hill-effect echoes, however, exhibit slightly longer durations than the urban-effect echoes. The potential urban-effect distribution is very similar to the no-effect distribution. The general relations between the various echo types in Table E-5 are very similar to those pointed out for maximum echo intensities in Table E-4.

Table E-6 summarizes the comparison of path lengths among the four echo types. Results show the same trends noted for maximum echo intensities and echo durations in Tables E-4 and E-5.

Echo speed comparisons are shown in Table E-7. There is very little difference in the frequency distribution of urban-effect and no-effect echoes. The potential urban-effect and hill-effect echoes illustrated somewhat greater speeds than the other two types, but the difference are not great enough in the relatively small samples of echo types to reach significant conclusions at this time.

Table E-6. Comparison of Path Lengths Between Echo Intensity Centers from Frequency Distribution Curves

Cumulative Percent of Echoes	Distance (Miles) Equalled or Exceeded for Given Echo Type			
	Urban Effect	Potential Urban Effect	No Effect	Hill Effect
10	14	13	9	15
20	8	9	6	10
30	6	6	5	8
40	5	4	4	6
50	4	3	3	4
60	3	2+	2	3
70	2-	2-	2	2+
80	1+	1	1+	2
90	1+	1+	1	1

Table E-7. Comparison of Speed of Movement Between Echo Intensity Centers from Frequency Distribution Curves

Cumulative Percent of Echoes	Speed (mph) Equalled or Exceeded for Given Echo Type			
	Urban Effect	Potential Urban Effect	No Effect	Hill Effect
10	33	42	34	34
20	26	34	27	28
30	21	28	22	23
40	17	22	18	20
50	14	17	15	17
60	12	13	12	14
70	10	10	10	12
80	8	7	7	9
90	5	5	5	7

Summary and Conclusions

Analyses were made of radar echo observations from 17 storms sampled with the 10-cm, FPS-18 radar during 1972-1973. Major emphasis was placed upon preferred areas of echo initiation and echo mergers in the METROMEX Network of 2100 mi^2. Results of the echo initiation analyses indicated a strong trend for echo initiations to occur most frequently in the vicinity of oil refineries at Wood River. Other regions of outstanding preference were located in South St. Louis and in the SE part of the St. Louis urban area. Overall, a relatively high frequency of echo initiations occurred in the urban-industrial regions of St. Louis and Wood River and E and NE of St. Louis in the Edwardsville-Collinsville-Belleville region where downwind effects would most frequently occur because of the pronounced trend for storms to move across the METROMEX Network with a westerly component. As expected, another region of high initiation frequency was in the Ozark foothills in the SW part of the network.

Analyses of the most frequent location of echo mergers, which are frequently associated with the intensification of surface rainfall, indicated a preference for the network area extending E and NE from St. Louis and Alton-Wood River. Again, this is the portion of the network that is most frequently exposed to potential urban effects.

Comparison of average properties of urban and non-urban echo intensity centers showed that those centers exposed to urban effects had longer durations, path lengths, and maximum intensity than the unaffected echo centers. This provides additional support for an urban enhancement effect.

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F. RHI FIRST-ECHO STUDY

Stanley A. Changnon, Jr.

Introduction

Research by the University of Chicago (Braham, 1974), using radar-detected locales and heights of first echo tops and first echo bases, has provided useful information on 1) the echo initiation patterns in the St. Louis area and Southern Illinois, and 2) the height differences between rural and urban echoes. The latter is useful in inferring urban causative mechanisms for urban area precipitation. These findings were of sufficient interest to pursue similar investigations using the Water Survey's TPS-10 radar (identical to that of the University of Chicago). The Survey's radar was at Pere Marquette Park, approximately 30 miles northwest of central St. Louis, and the Chicago radar at Greenville, about 45 miles east of St. Louis. Due to locational differences, the two radars did not scan the same areas except over St. Louis and the immediate downwind area. The Survey's radar scan included the area west (upwind) of St. Louis, whereas the Chicago radar scan enveloped the area east of St. Louis.

The Survey's TPS-10, a range-height 3-cm wavelength radar, was operated during portions of late July and the first 3 weeks of August 1973 to direct tracer aircraft operations. The mode of operation generally was directed towards narrow sector scanning (dedicated to closely observing one or two storms of interest) and to occasional and irregular scans over the METROMEX Research Circle. These operations seldom collected photographic data useful for a comprehensive, climatic oriented first-echo study. However, operations on three days were adequate for first-echo data. During the last 10 days of August 1973, the radar was operated continuously in a 200-degree sector scan mode, from 20° to 220° with St. Louis near the sector center at 145°. Scope photography was accomplished for each 1.8° beam width. First-echo data were collected on four of these days. The echo data sample is described in Table F-1. Great care was taken in choosing the first echoes, such that only one minute could have elapsed between the 'echoes' first appearance (defined as a first echo) and the prior scan of the area. This procedure resulted in the elimination of several "first echoes" that could have been in existence for two or three minutes. This makes a difference since growth and echo change are usually considerable in the first few minutes that precipitation is detectable with a narrow-beam, 3-cm radar set. This filtering process resulted in echo data on 8 days that included 170 first echoes. They occurred with two synoptic types, squall lines or zones and air mass storms.

Location

The sector from 85° to 190° and from 10 to 55 miles in range was sampled during all of the operational periods shown in Table F-1. For study of areal frequencies, this area was divided into four types of land use because prior analyses (Schickedanz, 1973) has shown differences between raincells in the 1) St. Louis urban area, 2) the Alton-Wood River industrial area, 3) the Mississippi-Missouri River bottomlands, 4) the Ozark Hill area, and 5) the rural area not included in 3 and 4 above.

Table F-1. First-Echo Data for August 1973

Date	Number of First Echoes	Period of Echo Activity	Synoptic Type with Echoes
7	12	1215-1830	Air Mass
10	14	1430-1800	Squall Line
12	14	1430-1930	Squall Line
13	2	1400-1500	Squall Zone
23	26	1120-2100	Air Mass
24	19	0840-1850	Air Mass
28	9	1500-1900	Air Mass
29	74	1400-2200	Squall Line

The resulting areal sizes and number of first echoes in each appear in Table F-2. When the frequencies are normalized to size of area, the results show that the Alton-Wood River and St. Louis urban area lead with averages of 2.3 and 2.1 echoes per 40 mi^2, respectively. These are about 50% greater than the bottomlands, and Ozark Hill area, and 300% more than the rural area value.

Table F-2. First-Echo Areal Frequencies on 7 August Days in 1973

Area	Square Miles in Area	Number of First Echoes	Average Number of Echoes per 40 mi^2	Number of First Echoes at Same Range(1) per 40 mi^2
Alton-Wood River	120	7	2.3	2.3
Bottomlands	200	7	1.4	
St. Louis	280	15	2.1	2.1
Rural	2,600	45	0.7	1.0
Hill	1,040	37	1.4	1.8
Total	4,240	105	1.0	1.5

---

(1) Based on range of urban area, 20 to 35 miles.

The frequencies at the same range as the St. Louis urban area were also counted and expressed as frequency per 40 mi^2 in the last column of Table F-2. This was done to correct for range-square sampling problems that might appear and effect the total area sampling. These results do show higher values for the hills and rural areas, but the urban value is still highest. A bottomlands value was not computed because of its closer range to the radar.

Although the sample size is not large, the first-echo results show there were greater frequencies in the urban areas than elsewhere, and this agrees with Braham's (1974) results.

Echo Top-Base Results

The heights of the bases and tops of the first echoes (FE) were investigated regionally and synoptically. The 104 FE produced during four squall line periods (see Table F-1) were sorted by occurrence in four regions: 1) the Ozark Hills, 2) the bottomlands, 3) the urban area (St. Louis plus Alton-Wood River), and 4) all other rural areas (essentially those N, NE, E, and SE of the radar and beyond St. Louis and Alton-Wood River). Average heights and bases were calculated for each location grouping, and these appear in Table F-3. Their dimensions are also repeated in Fig. F-1 for ease of comparison. The first echo analysis for squall lines shows: a) rural echo tops were highest followed by urban, b) the bottomlands echo bases were lowest, although the urban, hill, and bottomland bases were all more than 15 00 ft lower than the rural, and c) the urban FE had the greatest vertical extent at formation. The locale of formation of the 104 squall-line echoes apparently had a marked effect on precipitation formation.

In a similar fashion, the 66 FE that occurred during air mass conditions on four days (Table F-l) are summarized in Table F-3. There was no calculation for bottomlands FE because of the small sample, only 4 FE. Inspection of Fig. F-l. reveals certain interesting facts: a) the urban FE were taller and lower than the rural, hill area FE, b) the average air mass urban FE had a vertical extent more than 2500 ft greater than the others, and c) the air mass FE in all areas had less vertical extent and were lower than their comparable average FE for squall lines. Clearly, there are regional as well as synoptic differences in the precipitation processes.

The average tops and bases of all FE are also shown in Table F-3 and Fig. F-l. These show that the urban and bottomland FE were much the same, having lower bases than the hill and rural FE. They also had greater vertical extents, being markedly greater than the rural FE. The median values also are shown in Table F-3, and reveal that the averages are comparable in all but the height of the bottomland and rural FE, a few of which had either quite low or quite high tops, producing slightly biased averages.

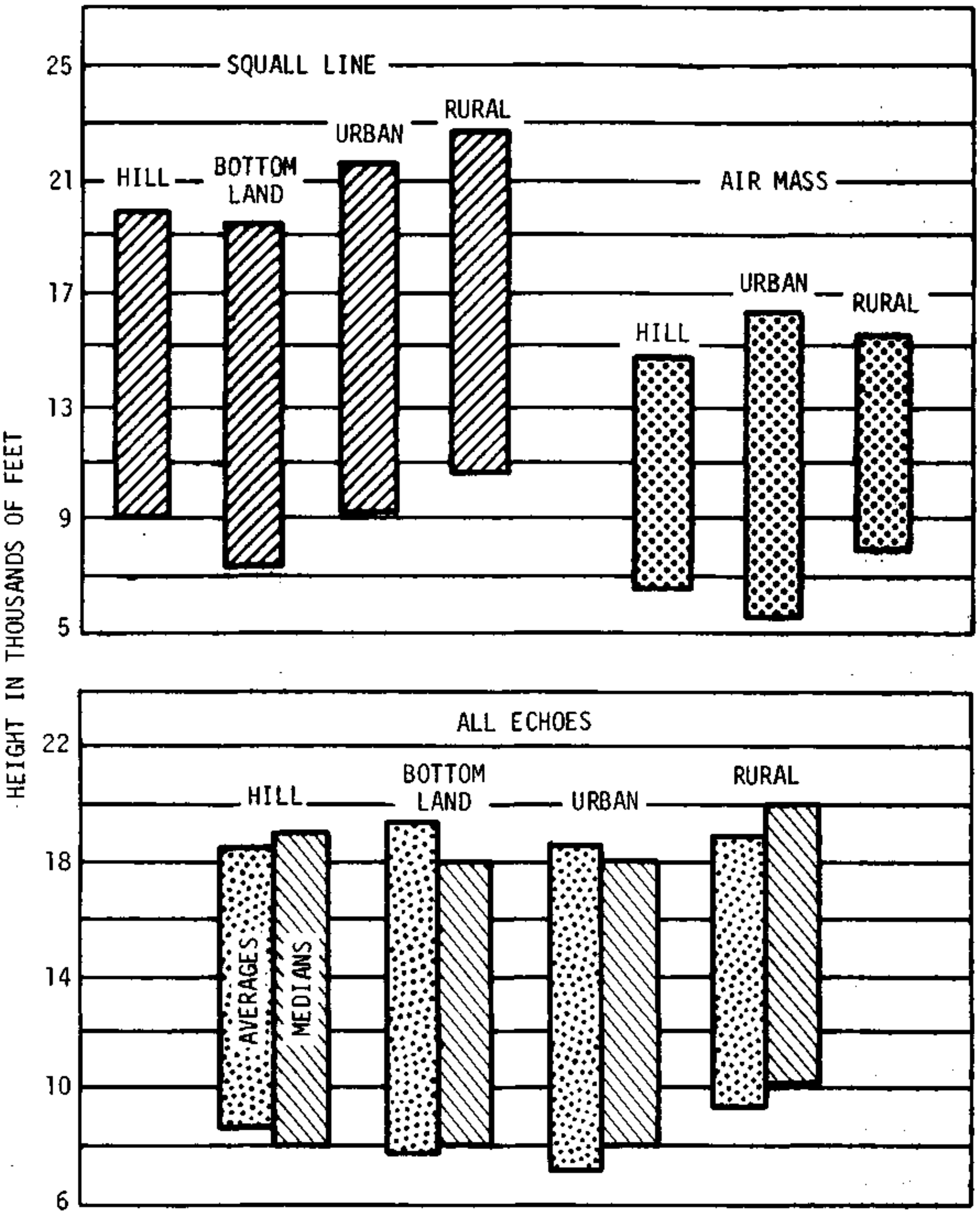

Figure F-1. Average height of tops and bases of ***TPS-10 echoes***

Table F-3. Average Heights of First Echo Tops and Bases in August 1973[1]

Squall Line-Zone Echoes

	Hill	Bottomland	Urban	Rural	All
Number	45	15	10	34	104
Tops	19,800	19,300	21,400	22,500	20,800
Bases	9,000	7,300	9,100	10,600	9,200
Vertical Extent	10,800	12,000	12,300	11,900	11,600

Air Mass Echoes

	Hill	Bottomland	Urban	Rural	All
Number	18	4	12	32	66
Tops	14,600	--	16,200	15,400	15,500
Bases	6,800		5,600	8,000	7,300
Vertical Extent	7,800	--	10,600	7,400	8,200

All Echoes[2]

	Hill	Bottomland	Urban	Rural	All
Number	63	19	22	66	170
Tops	18,400(19)	19,200(18)	18,600(18)	19,000(20)	18,700(19)
Bases	8,300(8)	7,700(8)	7,200(8)	9,300(10)	8,500(8)
Vertical Extent	11,100	11,500	11,400	9,700	10,200

[1] Dates: August 7, 10, 12, 13, 23, 24, 28, and 29.

[2] Median values in parenthesis beside each average.

Summary

The analysis of 170 FE on eight days in August 1973 revealed that there were distinct differences between formation frequencies for various land use or land types. The Alton-Wood River and St. Louis areas had 50 to 70% more FE than did other areas (bottomlands and Ozark Hills) where surface conditions apparently also affected FE frequencies. The frequency per unit area of FE in the urban areas were over 100% greater than in the rural area.

These regional differences in frequencies were also found in the average tops and bases of FE. Basically, the average bases of FE's over the urban area and river bottomlands were much lower than that over rural areas. First-echo dimensions also varied synoptically, being generally larger and higher in squall lines than in air mass storms. The air mass FE in the urban areas differed decidedly more from the other FE than did the urban FE with squall lines. Similarity in the urban and bottomlands FE suggests they result from similar processes, achieving coalescence more rapidly above cloud base than clouds over rural areas.

The results clearly indicate that urban effects are instrumental in the precipitation process. They lead to more echo initiations and the FE have lower bases.

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G. THUNDER DATA AND RESULTS FOR 1973

Stanley A. Changnon, Jr.

Introduction

The thunderstorm investigation was continued in 1973 to examine for the presence of urban effects on summer (June-August) thunderstorm activity. The analysis of 1973 data was comparable to that pursued in previous years. Climatic studies of limited historical data (Huff and Changnon, 1972) showed a local increase of 20% in thunder days, and the 1971-1972 METROMEX data showed a 25% increase in thunderstorm days in the area just east of St. Louis (Changnon and Huff, 1973).

The possible urban effect on monthly and summer thunder frequencies in 1973 was investigated using point data, and the type of effect was investigated by examining the nature of discrete thunder periods - their duration, time of occurrence, and thunder rate or frequency.

Data

There were two basic sources of data: 1) that from four standard weather observation stations (Lambert Field of NOAA, Scott Air Force Base, Pere Marquette Radar Site of ISWS, and Waterloo-NOAA cooperative observer); and 2) that from six automatic audio thunder recording units operated by the Water Survey. These 10 sites are identified in Fig. G-1. The automatic thunder recording stations each have four microphones and multi-channel recording that allows analysis of the direction of thunder arrival. Under certain circumstances, this capability allows identification of cells that are (or are not) thunderstorms and related details concerning changes in thunder frequency, as a function of cell growth and rainfall.

Three of these recorder sites, those farthest east (Fig. G-l), were installed in 1973 in response to a need (Changnon, 1973) to define the eastward extent of the high incidence area defined by the Scott Air Force Base and Edwardsville sites (see Fig. G-l) in 1971 and 1972. The new site operations began in early June, but those at the three older recorder sites in the Research Circle had started by 1 June. Days of thunder in early June were estimated for the 9-10 June openings of the "Far East" sites using rainfall patterns, echo motions, and field observer data.

The recorder data allow definitive assessment of the beginning and ending of thunder periods, defined as periods of thunder with two or more peals every 15 minutes. A period was ended when 60 or more minutes without thunder occurred. These data also allow investigations of the frequency of thunder per unit time. A group of point "thunder periods" that had time and space coherence with a precipitation system in the network area were used to define "network thunder periods".

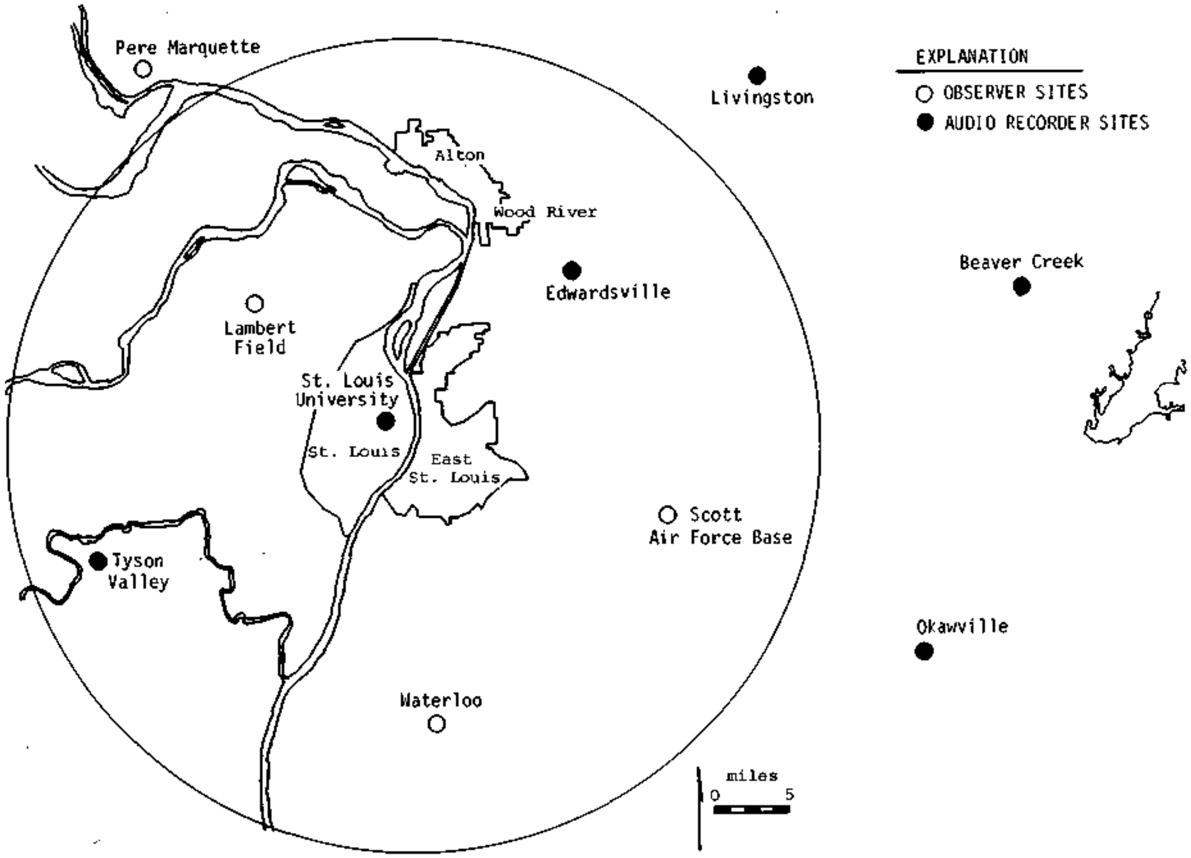


Figure G-1. Sites of thunder recordings and observations in 1973

Some of the future studies envisioned for the METROMEX thunder recorder data, once the 5-year sample is collected, include:

1. the question of distance of thunder audibility, to be studied for various atmospheric conditions;
2. the climatic aspects of times of first thunder from a storm after a) its first echo forms, and b) after first rain at the ground; and
3. comparison (for isolated echoes that can be properly identified) of the frequency of thunder against rainfall rate and echo growth (vertical and volume).

Results

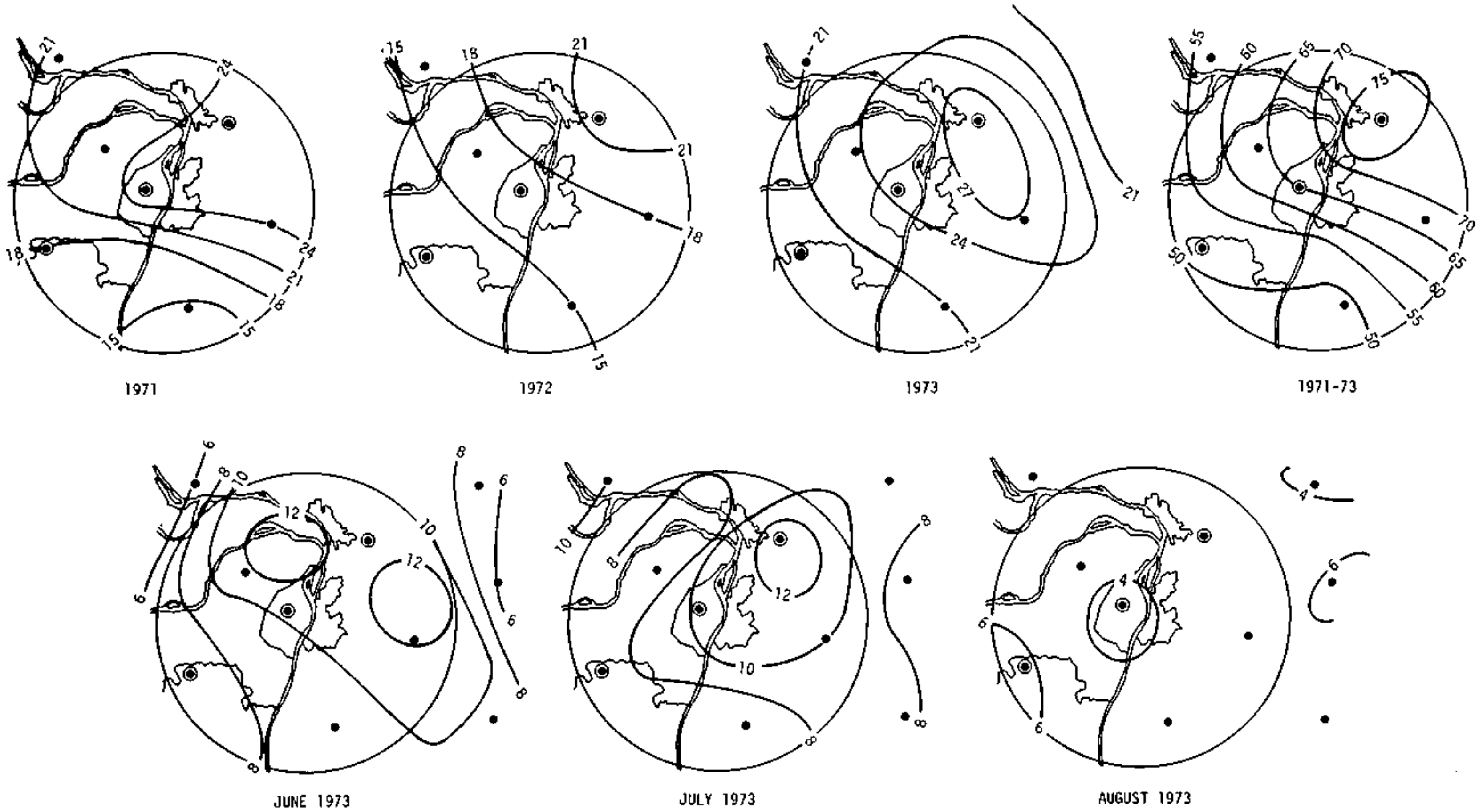
Daily. The dates of thunder at the 10 sites are listed in Table G-1. The 10 sites are located within a study area of 3800 mi^2, and each site represents a sample over 75 to 200 mi^2 (depending upon estimated audibility). Thus, the 10 sites sample between 750 and 2000 mi^2 of the total area. Obviously, some thunder could occur without detection, but consideration of prevailing storm motions and durations with respect to the uniform grid spacing of the 10 sites suggests that the most thunderstorms are detected.

The dates of thunder at one or more sites in the network (3800-mi^2 area) are listed in Table G-2. There were 16 days in June (53% of all days), 16 days in July (55%), and 11 in August (39%). Thus, in 1973 there were 43 dates with thunder, nearly 50% of the total days, or 1 out of every 2 days.

A comparison of the thunder-day frequencies in 1973 with those in prior METROMEX years can be achieved using the data in Table G-3. Here, the 1973 thunder dates based solely on the "Far East" sites, which were open only in 1973, are deleted. The 1973 total is quite comparable to those in prior years, but individual monthly frequencies differ.

Figure G-2 presents the 1973 monthly thunder day patterns. Highs in and immediately east of St. Louis appear in June and July, but the pattern for August is flat. The 1973 summer pattern has the high placement characteristic of the prior two summers. Both Edwardsville with 29 days and Scott AFB with 28 days have totals that are 7 to 9 days above the "background values" of 19 to 21 days at the sites west and east of the area of high incidence. Importantly, the three new "Far East" sites showed values comparable to those west of St. Louis and, thus, indicate that the urban-related increase was local in 1973. The 3-year pattern shows that the Edwardsville total of 76 days is 34% greater than the 57-day average west of St. Louis (Lambert, Pere Marquette and Tyson Valley). The Scott Air Force Base value of 70 days represents an increase of 23%.

Thunder-Rain Network Periods. The daily basis of thunder analysis does not allow study of the individual discrete rain periods which can exist in the network area several times on one day, or can affect two dates by occurring near midnight. There were nine such dates in 1973 with two distinct rain



1971 1972 1973 1971-73

JUNE 1973 JULY 1973 AUGUST 1973

Figure G-2. Monthly and seasonal isoceraunic (thunder-days) patterns periods, each with thunder. The se ape listed in Table G–2. There were 47 thunder-rain periods and these are tabulated by thunder distributions in Table G-4.

Table G-1. Dates of Thunder in Summer 1973⁽¹⁾

	Operational Dates	June	July	August
Observer Sites				
Pere Marquette	6/ 1 - 8/31	2,3,4,12,18,26	1,2,4,9,19,20,23,25,29,30	9,10,12,13,16
Lambert Field	6/ 1 - 8/31	2,3,4,5,12,17,18,19,21,24,26,27	4,9,23,25,27,29,30	9,10,12,13,29
Waterloo	6/ 1 - 8/31	2,3,4,5,11,12,14,24,26	1,9,14,23,29,30	9,10,12,13,29
Scott AFB	6/ 1 - 8/31	2,3,4,5,11,12,13,16,17,18,24,26	1,2,4,9,14,19,23,25,27,28,30	9,10,12,13
Audio Recorder Sites				
Tyson Valley	6/18 - 9/6	2,3,4,12,18,24,26	1,9,19,20,23,27,29	9,10,12,13,16,29
St. Louis Univ.	6/5 - 9/6	2,3,4,5,11,12,19,24,26,27	1,2,4,9,14,19,23,27,28,29,30	9,10,12,13
Edwardsville	5/29 - 9/1	2,3,4,5,11,13,17,18,19,21,26	1,2,4,9,19,20,23,24,25,27,28,29,30	9,10,12,13,29
Livingston	6/7 - 9/1	2,3,4,15,17,18,26	1,2,3,4,20,23,25,27,30	11,12,13,29
Beaver Creek	6/7 - 9/5	2,4,5,17,26,27	1,2,5,9,23,25	7,11,12,13,17,21,29
Okawville	6/13 - 9/5	2,3,4,5,12,14,21,26,27	1,2,9,14,19,23,24,25,27,28	10,12,13,17,29

(1) Dates at recorder sites in early June (prior to station operations) were estimated from a variety of other data.

Table G-2. 1973 Dates with Thunder in the Network (at 1 or more sites) and Thunder Periods⁽¹⁾

	June	July	August
Thunder Days	2 ,3,4,5 ,11,12 ,13,14, 15,17,18,19,21,24,26, 27	1,2 ,3,4,5,9 ,14,19, 20,23,24,25,27,28, 29,30	7,9,10 ,11,12 ,13, 16,17,21,29
Dates with 2 or more Network Thunder Periods	4(morning-afternoon and evening into the 5 June), 5(morning £ evening), 12(afternoon and late evening), 19 (morning £ evening), 24(early morning £ morning)	20(afternoon £ evening) 23(early morning £ afternoon), 24(early morning £ mid-day) 29-30(night) and 30(afternoon)	9(morning £ late afternoon)

(1) Dates when thunder occurred only at new Far East sites are underlined.

Table G-3. Number of Network Thunder Days in 1971, 1972, and 1973*

	1971	1972	1973	Total
June	17	12	14	43
July	9	10	14	33
August	11	12	7	30
Total	37	34	35	106

* Excludes dates in 1973 defined solely by the 3 easternmost sites which were not operating in 1971-72.

The areal distribution of the thunderstorm activity in 1973 and in the two prior years is shown in Table G-5. Widespread thunder activity at all sites has been of similar magnitude in all years, and the total represents 16% of all 117 thunder periods. Activity labeled as "west Only" means thunder only at Pere Marquette, Tyson Valley, and/or Lambert Field. These are locations west and "up-storm" of the urban complex, and activity is considered to represent no-urban effect or natural frequencies. The "East Only" class is based on thunder activity only at St. Louis University, Edwardsville, and/or Scott AFB, and is considered indicative of potential urban effects. The 1973 frequencies in each class were one less than in prior years but the east-west ratio of 2.3 was similar to those in 1971 (1.7) and 1972 (2.0). In the three years (1971-73), east-only thunder activity occurred 27 times or 23% of the total rain-thunder periods, whereas west-only cases have occurred 14 times or 12% of the total occurrences. The east-west ratio was 1.93, indicating a 93% increase in areal thunderstorm activity. Point-to-point comparisons show increases of 23 to 34%. Widely scattered cases are defined as those with thunder at one or more west site and one or more east site but not at all sites. Their frequency in each year has been relatively similar (Table G-5).

Inspection of the synoptic results (Table G-6) reveals that the east-only (potential urban-effected) occurred most often in 1973 during the cold frontal and air mass cases (4 of 7 rain periods). All three of the west-only (natural and/or urban dissipation) thunder-rain periods occurred with squall area conditions. Of interest is the fact that all six of the "all sites" cases of thunder occurred with rain periods produced by squall lines.

Table G-4. Number of Thunder (Rain) Periods in 1973 by Areal Distribution in Study Period

	Number per location					
	Widespread at all Sites	Widely Scattered	West Only	East Only	Far East Only	Total
June	3	8	0	5	2	18
July	1	11	1	2	3	18
August	2	3	2	0	4	ll
	6	22	3	7	9	47

Table G-5. Thunder (Rain) Periods with Thunder Classified as to Placement of Thunder Activity in the Network

	Widespread at all Sites	Widely Scattered	West Only	East Only	Far East Only	Total
1971	8	17	6	10	--	41
1972	5	18	5	10	--	38
1973	6	22	3	7	9	38 (47 including Far East)
Total	19	57	14	27	9	117
Percent of Total*	16	49	12	23	--	

* Excludes Far East only occurrences, and are based on 3-year total of 117 periods.

Table G-6. Synoptic Weather Types with Network Rain Periods having Thunder in 1973

Synoptic Class	All Sites	Widespread Scattered Thunder	West Only	East Only	Total
Cold Frontal	0	1	0	2(67%)	3
Warm Frontal	0	2	0	0	2
Post Cold Front	0	0	0	1(100%)	1
Air Mass	0	1	0	2(67%)	3
Squall Line	6	9	0	1	16
Squall Area	0	8	3(25%)	1	12
Stationary Front	0	1	0	0	1

Point Thunder Periods. Another means of investigating local differences in thunderstorm activity consists of comparing the number, duration, and rates of thunder in thunder periods at a point. The number of thunder periods and their average durations are listed in Table G-7. The averages for Tyson Valley, St. Louis, and Edwardsville were all less than their averages for 1971-1972. No real duration pattern emerges from these comparisons.

The 1973 data from the recorder sites were also analyzed to determine the number and durations of the different rates of thunder occurrences per unit time. Observed rates were classed as 1) single stroke (1 per hour), 2) few (rate of 2 or 3 peals per hour, 3) occasional (4 to 11 per hour), 4) moderate (12 to 60 per hour), and 5) intense (>60 peals per hour, or 1 per minute). The number in each class at the six stations is shown in Table G-8. The totals show a definite west-to-east increase, but the high values at Livingston and Beaver Creek were largely due to many single strokes. The frequencies of moderate and intense occurrences are also shown in Table G-8. This reveals that Edwardsville and Okawville had many more occurrences (38 and 34, respectively) than did the other sites (11 to 21 such periods).

The thunder rates were also investigated on the basis of durations, and the total and average durations in each class are shown in Table G-9. The "effect site", Edwardsville, did not have the most total minutes of thunder nor exceptionally longer averages in any class. However, the totals for intense and moderate thunder show Edwardsville had 1800 minutes, more than that at the other sites.

The average number of thunder periods per day of thunder was also computed. These averages (Table G-7) show that St. Louis and Edwardsville had nearly two periods on each day with thunder. Other nearby locales averaged about one thunder period per day. This suggests that urban-related effects led to more distinct thunderstorm events per day of activity. Thus, the urban effect on thunderstorm activity was to produce more days of thunderstorms and also to produce more activity (storms) on a day when storms were already occurring.

Table G-7. Number of Thunder Periods in 1973 and Average Durations and Daily Frequencies

	Number of Periods	Average Duration, Minutes*	Average Number of Periods Per Thunder Day
Tyson Valley	19	73 (137)*	1.1
St. Louis	34	67 (176)*	1.9
Edwardsville	48	58 (184)*	1.7
Livingston	23	24	1.3
Beaver Creek	22	45	1.3
Okawville	23	67	1.2

* 1971-72 averages

Table G-8. Number of Occurrences in Five Classes of Rates of Thunder for Each Recorder Site

	Number of Occurrences					
Thunder Rate Class	Tyson Valley	St. Louis Univ.	Edwards-ville	Living-ston	Beaver Creek	Okaw-ville
Single Stroke	44	27	47	144	171	56
Few	5	22	14	7	59	27
Occasional	8	15	10	12	24	36
Moderate	9	4	17	7	4	12
Intense	12	13	21	4	9	22
Total	78	81	109	174	267	153
Number of Moderate and Intense	21	17	38	11	13	34

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(1) Few = Rate of 2 to 3 peals per hour, occasional = 4 to 11/hr. , moderate = 12 to 60/hr., and intense - >60/hr.

Table G-9. Total and Average Duration of Each Class of Thunder Rate at Each Recorder Site

	Duration, minutes											
	Tyson Valley		St. Louis Univ.		Edwards-ville		Living-ston		Beaver Creek		Okaw-ville	
Rate Class	Total	Ave	Total	Ave	Total	Ave	Total	Ave	Total	Ave	Total	Ave
Few	158	32	1053	48	220	16	133	19	1955	33	789	29
Occasional	448	56	864	57	554	55	140	12	933	39	1387	39
Moderate	585	65	214	53	697	41	142	20	238	60	686	57
Intense	808	67	804	62	1103	53	87	22	133	27	914	41
Total	1999	--	2935	--	2574	--	502	--	3259	--	3776	--
Total Moderate £ Intense	1393		1018		1800		229		371		1600	

Diurnal Distribution. The diurnal distributions of thunder activity were analyzed by counting the number of times a thunder period occurred in each of the eight 3-hour periods of the day. For example, a thunder period that occurred between 0430 and 0610 CDT resulted in a count for the 0301-0600 CDT period and one for the 0601-0900 period. The number of occurrences at nine sites (no hourly data were available at Waterloo) appears in Table G-10. All sites show a mid-morning minimum with a maximum in the late afternoon (1501-1800 CDT) or early evening (1801-2100 CDT).

To examine for spatial differences, the data in Table G-10 were grouped by regions and then averaged to get area averages. The areas developed were West, East, and Far East, and the three stations in each area are listed in Fig. G-3. East is the area of increase in thunder days and number of periods, which is suspected as reflecting urban enhancement. The values of the West and Far East reflect unaffected or background values. The results, in general, support those of 1971-1972. The effect (East) area has more thunder in most hours of the day, but the greatest difference occurs between 2100 and 0300 CDT. This indicates that urban-related enhancement of thunder activity with precipitation is greatest at night.

Direction of Thunder. The data from the six audio recorder sites allow assessment(1) of the direction from which thunder occurred. These data are being used in case study analyses to investigate, when possible, which individual storm cells were thunderstorms and to determine the initiation of thunder, its rate, and cessation time. When this can be done for individual cells, changes in thunder rate are also studied to compare these with other storm characteristics such as echo height, rain rate, and hail production.

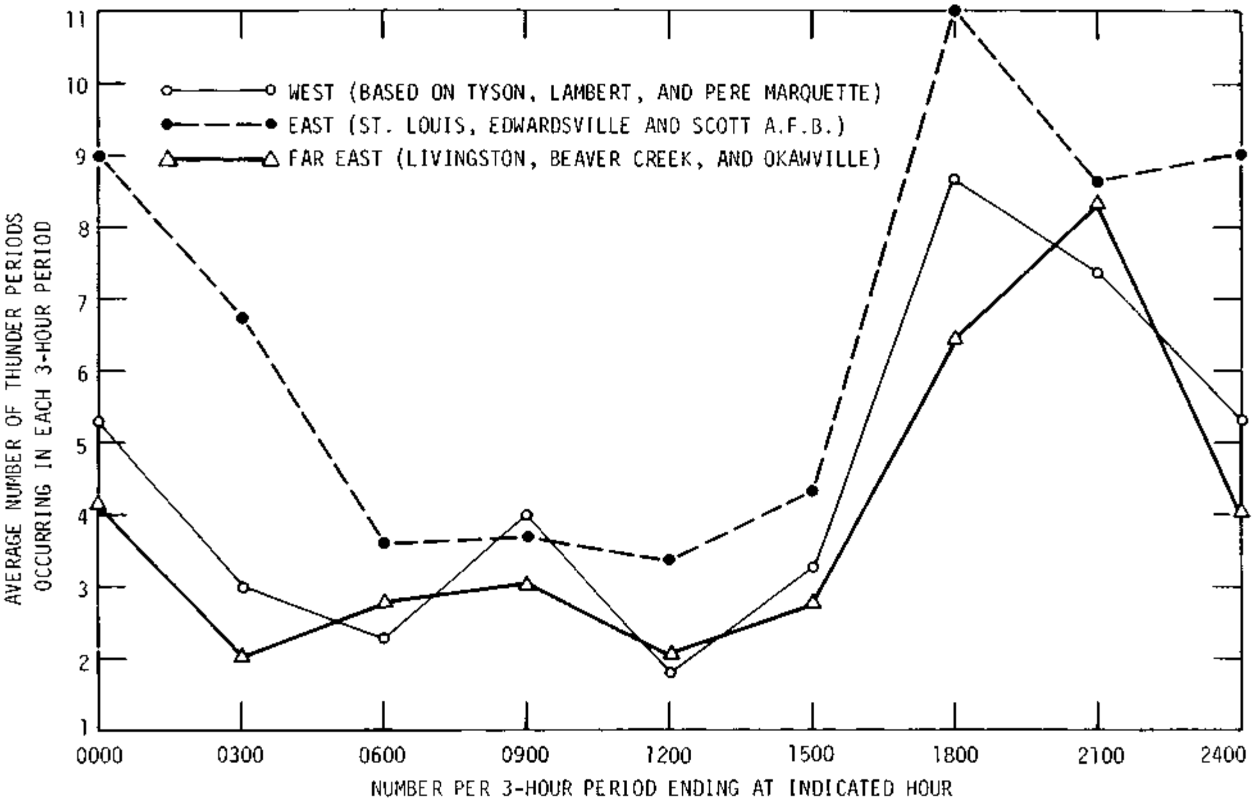

Figure G-3. Diurnal distribution of thunder periods in summer 1973

Table G-10. Number of Thunder Periods in Each 3-Hour Period in 1973

Period (CDT)	Scott AFB	Lambert Field	Pere Marquette	Tyson Valley	St. Louis	Edwardsville	Livingston	Beaver Creek	Okawville
0001-0300	10	6	2	1	2	8	2	1	3
0301-0600	3	3	3	1	5	3	1	3	4
0601-0900	3	3	4	5	5	3	3	5	1
0901-1200	3	1	2	2	4	6	2	2	2
1201-1500	4	2	5	3	4	5	1	2	4
1501-1800	10	8	9	9	12	11	3	6	10
1801-2100	9	9	9	4	9	8	8	7	10
2101-2400	8	9	4	3	6	13	7	3	2
Totals	50	41	38	28	47	57	27	29	36

Summary

The number of thunder days in the summer of 1973 was similar, both in frequency and in pattern, to those for 1971-1972. Thunder frequencies in 1973 were not greater than those in 1971-1972, eventhough 1973 was a wetter year. The number of days with thunder in the enlarged METROMEX Network (3800 mi^2) was 43, almost 1 out of every 2 days.

There were three new thunder stations established in 1973 to the east of the main study area in an attempt to define the eastward extent of the high shown in 1971 and 1972 at Scott AFB and Edwardsville. The 1973 data at these three sites showed lower values than those in and just east of the city, and these lower values were comparable to those at points west of the urban area. This indicates that the urban-related increase in thunderstorms is localized and within an area of 1000 to 2000 mi^2.

Measurement of the local increases in thunderstorm activity can be made in various ways using the 1973 data. The point-to-background differences suggest a 21 to 32% increase, whereas the area differences (West vs. East, or East vs. Far East) in frequencies showed increases of 135 to 150%. Durations of thunder periods showed no systematic west-east increase in 1973, and this differs with 1971-72 results. However, the number of thunder periods in 1973 at "effect sites" was 40 to 60% higher than the "background average".

Study of the 1973 rates of thunder peals at the six recorder sites revealed that the Edwardsville site had more (10 to 300%) discrete periods of moderate (12 to 60 peals/hr) and intense (>60 peals/hr) rates than other sites. Further, Edwardsville had more minutes of these moderate to intense rates than other sites. This suggests that urban effects lead to more frequent electrical activity.

Synoptically, the urban enhancement of thunder, based on location of activity, showed it was most prevalent in cold frontal and air mass storms. The 1973 results agree closely with those of 1971-1972, including the fact that there may be a decrease in thunder activity in the east in squall area situations. The diurnal investigation showed there was no appreciable regional difference in the 0300-1500 period, but that the increased activity east of St. Louis occurred largely in the 1500 to 0300 period, being greatest between 2100 and 0300 CDT. This nocturnal period of greatest effect also agrees with the 1971-1972 findings.

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H. HAIL DATA AND RESULTS FOR 1973

Stanley A. Changnon, Jr.

Introduction

The METROMEX hail investigations were continued in 1973 to examine for the alteration in hail characteristics or frequency as a result of urban effects. The 1973 data collection and analysis were identical to efforts in 1971 and 1972. Local climatic studies had indicated a 150% localized increase in the number of days with hail (Huff and Changnon, 1973), and METROMEX data for 1971-1972 indicated an 80% increase in an area 5 to 20 miles east of St. Louis (Changnon, 1973a). Crop-hail insurance loss records had substantiated this with a maximum loss area 10 to 20 miles ENE of St. Louis (Changnon, 1973b).

The data on hail in the summer of 1973 came from two sources. A 1-ft^2 hailpad served as a passive hail sensor at each of 244 raingage sites. These hailpads allow calculation of the number and sizes of hailstones and the impact energy. The raingages themselves were modified to record the time of hail. These two sets of data were used to count and measure hail days and hailfalls at points (discrete periods of hail), and to map hailstreaks (areas of hail with space and time continuity). Efforts were made to define hailfall durations, hailstreak durations, rain with hail (the amount from the hail-producing cell), and hailstreak area.

Spatial Distribution

The 1973 hail data are summarized in Table H-1. Hail fell during 19 different rain periods including 8 in June, 7 in July, and 4 in August. For each period, the number of points with hail west of a north-south line through the center of St. Louis and the number east of this line were determined. This is one method to separate potential urban-effected hailstorms from no-effect storms on a regional basis. Comparison of the west and east values on a rain-period basis showed a) greater frequency in the west on 3 occasions, b) equal frequency on 3 occasions, and c) a greater frequency in the east on 13 occasions. The 1973 totals showed 127 points with hail in the east and 74 points in the west. This E-W ratio is 1.7 compared with a ratio of 1.7 in 1971 (31 to 18) and 2.3 in 1972 (75 to 32). There were many more hailfalls in 1973 than in the two prior years, and 1973 was much the wettest of the 3 years.

Another method of evaluating the urban effect on hail is to compare storm periods. In three periods (6/12, 7/29-30, and .8/29) all hail fell from "effect raincells" (those that developed or crossed over St. Louis or Wood River). During three other periods (6/4, 6/11, and 7/29) all hail fell from

Table H-1. Summary of 1973 Hail Data

Rain	Network Hail Time (CDT)		Synoptic Weather	Largest Hailstone (diameter,	Number of Points with Hail		Hailstreaks Classed by Urban Effect		Average Point Energy-in Hailstreaks (ft lbs/ft2)	
Date	Begin	End	Type	inch)	West	East	Effect	No-Effect	Effect	No-Effect
6/ 4	0145	0210	Squall Area	0.45	13	1	0	13	None	0.0274
6/ 4- 5	2202	0216	Squall Line	1.25	1	22	12	2	0.1730	0.0506
6/ 5	1610	1615	Squall Line	0.25	0	3	2	1	0.0039	0.0028
6/11	1530	1540	Squall Area	0.75	1	1	0	2	None	0.2964
6/12	1820	1825	Squall Line	0.50	0	2	2	0	0.0267	None
6/13	0042	0208	Cold Front	0.50	0	3	2	1	0.0355	0.0139
6/18	1929	2132	Squall Line	1.00	19	37	22	25	0.0888	0.0697
6/26	1955	2100	Squall Line	0.75	0	4	3	1	0.2565	0.0033
7/ 9	1645	1650	Squall Line	0.75	1	1	1	1	0.7821	0.0050
7/23	1736	1826	Squall Line	0.65	6	6	6	5	0.1352	0.1208
7/25	2025	2158	Cold Front	0.40	2	3	3	2	0.0286	0.0191
7/27	2214	2351	Stationary Front	0.50	10	7	3	10	0.1593	0.0656
7/29	1628	1915	Warm Front	0.75	0	3	0	3	None	0.3089
7/29-30	2231	0023	Warm Front	0.37	0	15	9	0	0.0132	None
7/30	1602	1831	Squall Line	0.90	12	4	2	8	0.0887	0.1439
8/10	1450	1755	Squall Area	0.75	2	3	2	1	2.9787	0.0162
8/12	1504	1842	Squall Line	2.00	13	24	22	9	3.9065	0.0742
8/13	1439	1603	Squall Line	0.85	7	10	8	6	0.5651	0.2497
8/29	1820	1844	Squall Area	0.40	0	2	2	0	0.0114	None
Totals					87	151	101	90		

no-effect raincells (those that did not cross either urban area). Thus, no increase in hail days was shown, although the 1971-1972 results showed an 80% increase (9 effect only cases to 5 no-effect only cases).

On the 13 other 1973 days, hail fell from both effect and no-effect raincells. Comparison of these days clearly suggests hail enhancement related to urban factors. The number of effect hailstreaks on these 13 days exceeded the number of no-effect streaks on 9 days, whereas no-effect frequencies were greatest on 3 days (1 day was a tie). The total number of effect hailstreaks on the "both-type" days was 94 (an average of 7 per period) compared to 63 no-effect hailstreaks (a period average of 5). These results suggest a 49% enhancement of hail cores in effect raincells during conditions of natural hail production.

Comparison of mean energy values computed for the effect and the no-effect hailstreaks in each hail period (Table H-1) shows the clear predominance of higher energy values in urban-effect storms. Effect energy values were highest in 15 of the 19 periods. Thus, these results suggest near consistent urban increase in hail intensity (amount of hail, size of hail, and winds), as well as an increase in the number of hail elements (streaks).

The frequency of hailstreaks was less on those days with effect only than on days with no-effect only hailstreaks. The average number of no-effect hailstreaks was three compared with two for effect streaks. The difference is in good agreement with the 1971-1972 results.

The pattern based on the point frequencies in 1973 appears in Fig. H-l. The summer average point hailfall in St. Louis , as based on long-term records , is 0.4, or two hail days per five years. Thus, all values of one or more are above average. Large areas of zero values appear west of St. Louis, and smaller areas to the NE and SE.

The maximum incidence area (values of 4 hail days out of the 19 in the network in 1973) occurred just east of the central urban area which had shown a secondary maximum in 1971-1972 (Changnon, 1973a). Other areas of high incidence (3 values) were farther east, to the extreme west (where 1973 rainfall was high), in the bottomlands west of Alton, and in several locales to the east. Basically, the 1973 pattern was not unlike those of 1971 and 1972.

The 1973 hailfall values were combined with those of 1971-1972 to prepare Fig. H-2. The 3-year point average is 1.2 days, and all values ≥ 2 are above average. Areas of < 1 are below normal and these occurred largely SW and SE of St. Louis. The three major highs (values ≥ 4, or > 300% of normal) were located 1) immediately east of St. Louis in and along the American Bottoms, 2) farther east, SSE of St. Louis, and NW of the city in the Mississippi-Missouri floodplain. The two major highs were located east of St. Louis and point occurrences all resulted from storm cells that crossed, or developed, over St. Louis or Alton-Wood River. Many of the point values in the 4-value high SE of St. Louis also came from storms moving from the NW across the city. The 3-year pattern strongly suggests urban effects on hail and supports the pattern of losses to crops (Changnon, 1972).

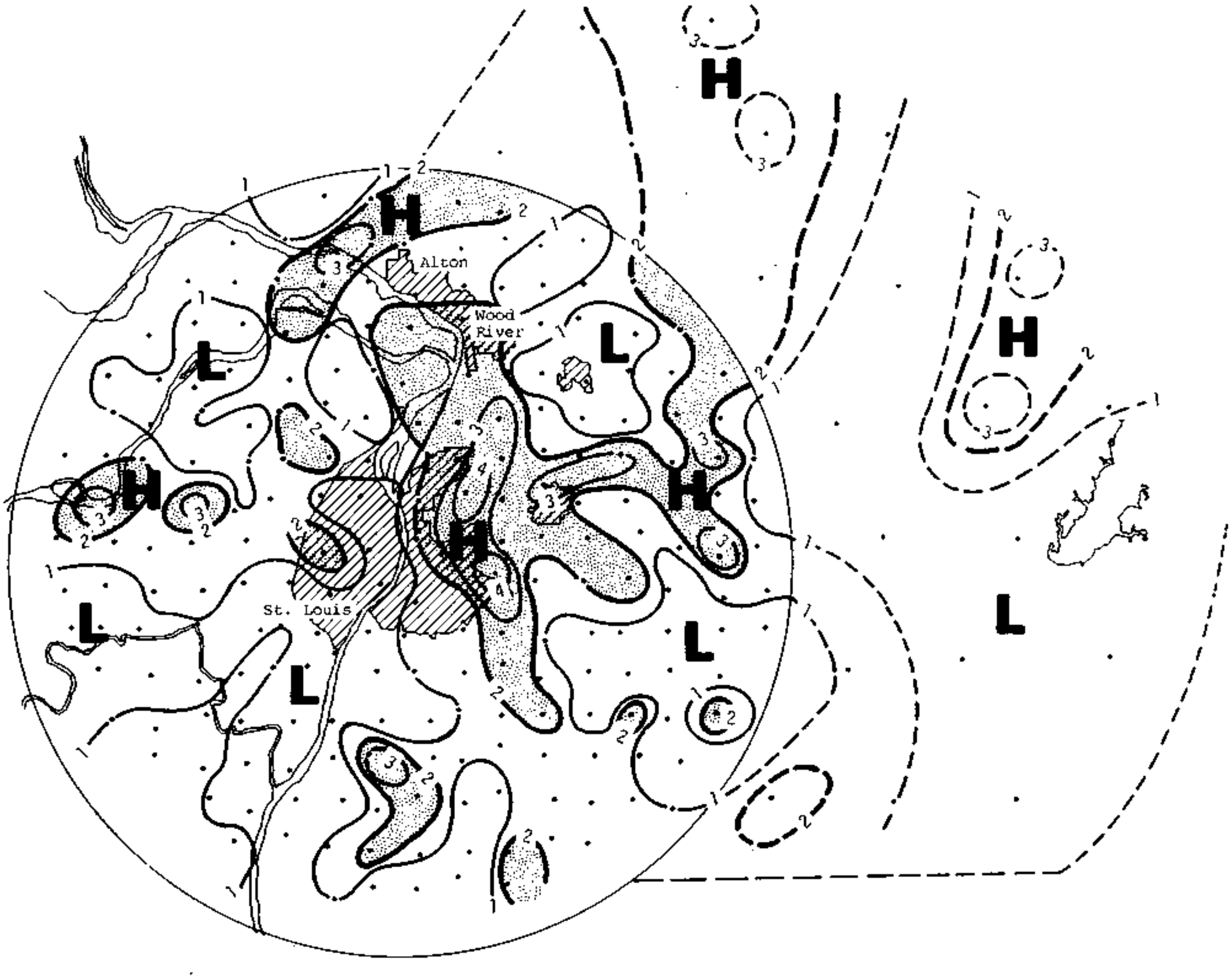

Figure H-1. Pattern based on point hailfalls in sunmer 1973

Figure H-2. Pattern based on point hailfalls in summers of 1971-1973

Hailstreak and Hailfall Characteristics

The major assessment of differences in hailstreaks and hailfalls due to urban effects was based on separation of hail events according to their parent raincell. If the cell crossed or developed over the city, the rain and hail were labeled as potential urban effect, and those that did not cross were classed as potential no-effect. Obviously, each class could contain cases that were not properly classified, but this serves as a useful classification method that raincell analyses have shown to be meaningful (Schickedanz, 1973).

This classification was used to develop the results in Table H-2. The ratios of effect to no-effect for 1973 are presented, along with the ratios from 1971-1972 data for comparison. The effect hailstreak frequency was 10% higher, effect size was 6% larger, duration was 30% greater and energy was 300% greater. The values of average duration and median energy were quite close to those of 1971-1972, but streak sizes in 1973 were about 1-mi^2 smaller.

The effect point values for hailfall also were greater than no-effect values. The number of hailstones in all size classes ranged from 70% to 350% greater. Point hailfall durations in effect streaks were 60% longer, and the associated rainfall was 20% heavier. The 1973 average hailfall values for sizes, rain, and durations were all greater than those found for 1971-1972. Clearly, the effect hailstreaks and hailfalls of 1973 were in a different class than the no-effect hail. The effected hailstorms occurred oftener, lasted longer (point and over an area), came with more rain, produced more hailstones of all sizes, and produced more impact energy.

Importantly, the 1973 E-NE ratios (Tables H-2) were not dissimilar to those obtained for 1971-1972. Some were smaller and some larger, but a general similarity exists. This suggests that the sample size is becoming adequate and shows that results are consistent and strongly indicative of urban effects.

Temporal Distributions

The times of occurrence of the 101 effect hailstreaks and the 90 no-effect streaks were sorted and counted according to 3-hour periods. Neither class had any hailfalls in the 0300-1200 period. The totals were alike in all but two periods. The effect hailfalls were 65% greater in the 1500-1800 CDT period and 56% higher in the 2100-2400 CDT period. These two periods of greater effect frequency matched exactly the results found in 1971-1972 (Changnon, 1973a).

Synoptic Weather Conditions with Hail

Hail periods occurred with five synoptic classes (Table H-1), but largely with squall lines (10) and squall areas (4). Comparison of classes based 1) on the number of effect and no-effect hailstreaks per period, and

2) on whether the effect or no-effect area had the highest energy per period revealed that urban-effect conditions were most prevalent in squall line and cold front storms. The effect energy value was higher in 9 of the 10 squall lines and in both cold front storms. The number of hailstreaks in the effect area was higher in 7 of 10 squall line cases and in both of the cold front cases.

Table H-2. Comparison of Characteristics of Hailstreak and Hailfall from Potential Urban-Effect Raincells with those from Non-Urban Effect Cells in 1973

Characteristic	Effect	No Effect	Ratio, E-NE	
			1973	1971-1972
Number of hailstreaks	101	90	1.0	1.4
Hailstreak, average duration (min)	15.5	11.5	1.3	1.2
Hailstreak, average area (mi^2)	5.2	4.8	1.1	1.2
Hailstreak, median energy (ft lb/ft^2)	.0505	.0170	3.0	6.1
Average number of hailstones per hailfall				
1/8" diameter	66	42	1.7	1.4
1/4" - 3/8"	10	3	3.3	3.0
1/2" - 5/8"	2	1	2.0	2.0
3/4"	0.6	0.2	3.0	2.0
Total, all sizes	79	46	1.7	1.7
Hailfall, average duration (min)	3.9	2.8	1.4	1.0
Hailfall, average rainfall (inches)	0.94	0.78	1.2	1.1

Summary

The study of hail in 1973 produced results which showed that 1973 experienced much more hail than 1971 or 1972. However, most of the results for 1973 on hailstreaks, hail days, and hailfalls were quite similar to those of 1971-1972. The results further substantiated the conclusions from the 1971-1972 data and from the earlier climatic studies (Huff and Changnon, 1972) which indicated that the St. Louis urban area produces sizeable increases in hail.

The 1973 increases came in the late afternoon and mid-evening. The 1973 downwind (east of St. Louis) increases produced by urban-effect storms are shown below, along with 1971-1972 values in parentheses:

Number of hail incidences - 173% (200%)
Number of hail days - 0% (80%)
Number of hailstreaks - 10% (40%)
Number of large hailstones (≥1/2 inch diameter) - 210% (250%)
Impact energy of hail - 300% (600%)

The typical urban-related hailstreak was larger, longer-lived, produced more hailstones, greater impact energy, and occurred with more rain than hailstreaks in non-effect cells. Synoptically, the 1973 results showed hail enhancement in urban-effect storms occurred most often with squall lines and cold fronts. This is in total agreement with the 1971-1972 results.

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I. SURFACE TEMPERATURE, MOISTURE, AND WIND STUDIES

Douglas M. A. Jones and Paul Schickedanz

Introduction

At the start of METROMEX in 1971 there was no major commitment to the intensive measurement of surface temperature, wind and moisture fields. The Water Survey used available equipment for installation of some 9 recording temperature-humidity stations and 6 wind stations in the 2000 mi^2 research circle and the University of Wyoming performed occasional surface cross-sections with their two mobile samplers. Review of project data in 1971-1972 revealed the value of these surface data in explaining the precipitation anomalies, and the surface temperature-humidity network was expanded and its density increased, largely through borrowed instruments, to 27 stations. Lack of adequate manpower for calibration and servicing resulted in loss of more data than desired. In 1973 the surface network data were found to be of further value through our cloud modeling results, and greater human resources were deviated, both in 1973 and 1974, to the temperature-moisture network effort.

The main goals of this effort initially was to provide a good climatic-scale description of the surface temperature, wind, and humidity anomalies, if any, in the urban area. A second goal that developed later was the use of these data in case study analyses of rain events in the area, and a final use has been to use the data in identifying local area sources of heat and in moisture and their effects of cloud and rain development.

Data Collection and Evaluation

The surface network of temperature and humidity recorders is shown in (Fig. I-1). Each of these sites included a Cotton Region shelter containing a hygrothermograph. One type of hygrothermograph had a bimetallic curved-metal temperature sensor and a bundle of human hairs as the humidity sensor. The other type of hygrothermograph used a bourdon tube temperature sensor and a harp of human hairs as the humidity sensor. Both types recorded on clock-driven drums largely with weekly recording. However, several instruments were converted to daily recording during August 1973. The shelters were not equipped for forced-air ventilation. An additional site was opened west of St. Louis in 1973, and instruments were operated from 1 June through 31 August in both 1972 and 1973.

Quality control of the temperature and humidity data was obtained in 1972 by having a single technician service all instruments, changing the charts, and checking temperature and humidity recordings by sling psychrometer readings at the time the charts were changed. From these check readings, corrections were made to the recordings when the chart data were digitized. The dew point temperatures were calculated from the corrected readings.

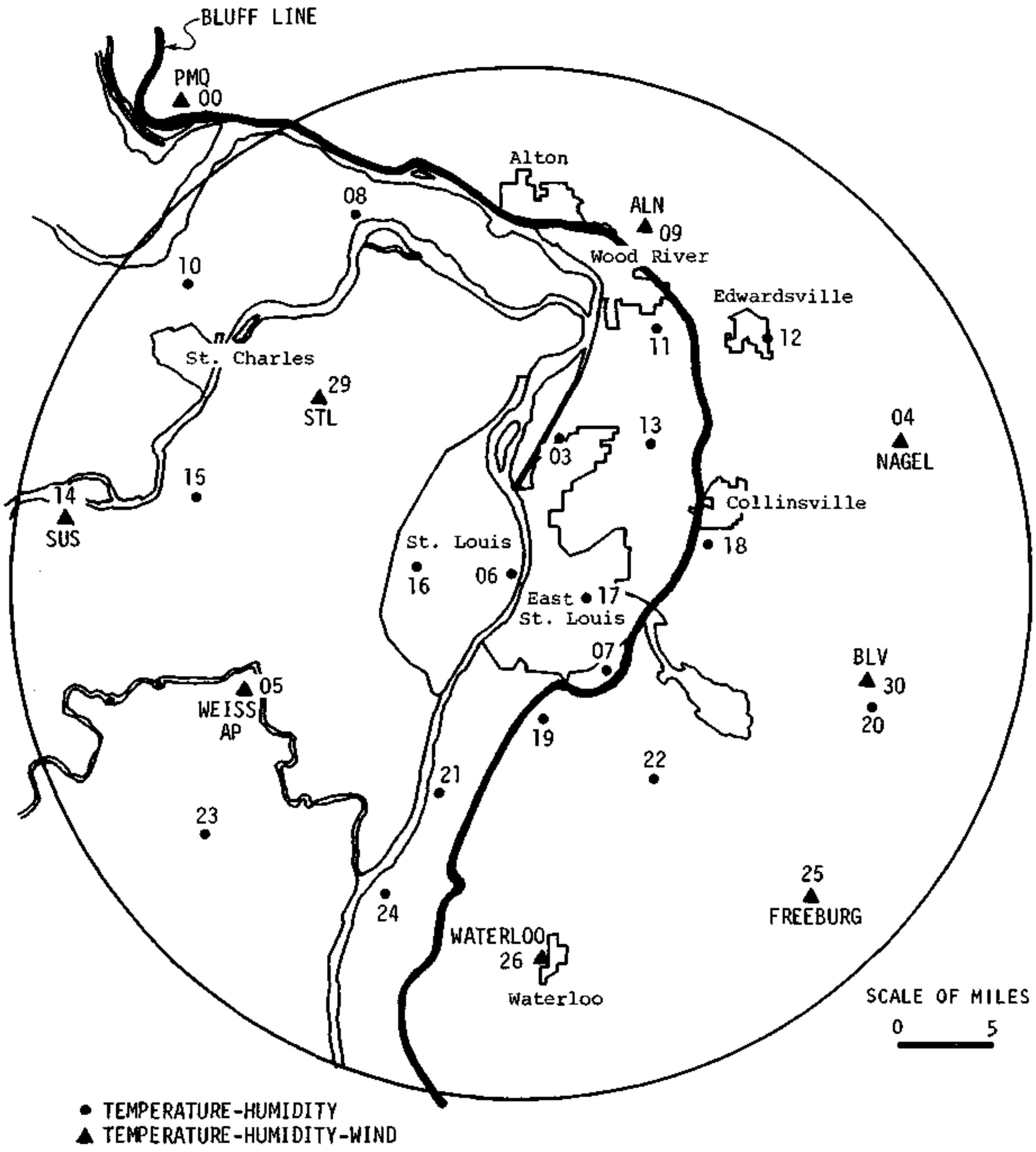


Figure I-1. Hygrothermograph and wind network

In 1973, the humidity was checked as in 1972 by sling psychrometer readings at the chart change by a single technician. However, in 1973 the temperatures were checked against a minimum thermometer suspended in each shelter. These minimum thermometers had been calibrated against a standard thermometer in a stirred water bath at atmospheric temperatures. Thus, the temperatures recorded in 1973 should be somewhat more reliable than those recorded in 1972. An estimate of the accuracy of temperature in 1972 is ±1.5°F and in 1973 ±1.0°F. Humidity accuracy in both years is no better than ±5%.

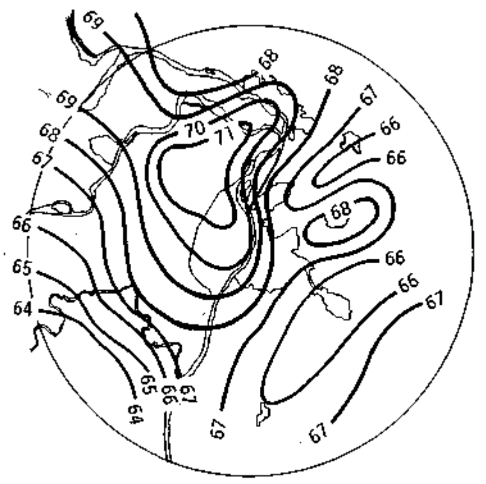
Average Air and Dew Point Temperatures

Examples of the mean temperature fields at 0600 and 1500 CDT for August 1972 have been provided by Jones (1973a). Similar analyses have been made for 1973 and are illustrated in Figs. I-2a to I-2f. Although the absolute values of the surface temperatures for the individual months as measured at the METROMEX sites in the three summer months of 1973 (June, July, and August) were not the same, the patterns of the temperature fields were not significantly different for a specific hour for each month. For 1973, the data have been further stratified into hours with clear to partly cloudy, broken, and cloudy skies as specified by visual observation at the National Weather Service Office at Lambert-St. Louis International Airport (STL). Although the STL sky conditions may not have been existed exactly throughout the circle, they constitute a reasonable available estimate for a summer.

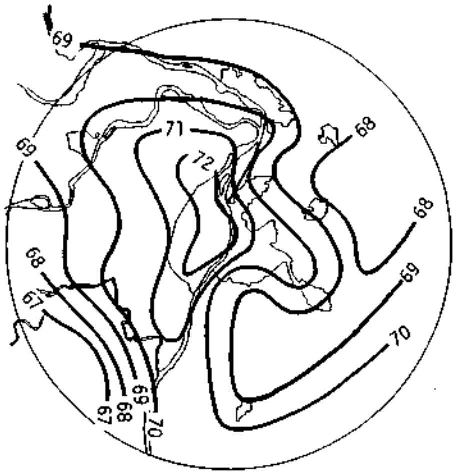
Of particular interest in the temperature fields is the decrease in intensity of the temperature anomaly apparently associated with the metropolitan area from 0700 to 1500 CDT on the clear to partly cloudy days (Figs. I-2a and I-2b). However, this change in temperature gradient becomes less as the sky cover increases until the overcast field at 1500 CDT (Fig. I-2f) indicates a stronger gradient than its counterpart at 0700 CDT (Fig. I-2e). This result may be caused by the small sample size for the overcast skies, on the order of six cases for three months.

Another noteworthy feature of the comparison of the 0700 and 1500 CDT charts is that a metropolitan heat anomaly is to be found on the 1500 CDT charts as well as at 0700 CDT. The intensity of that anomaly at 1500 CDT increases as the sky cover increases.

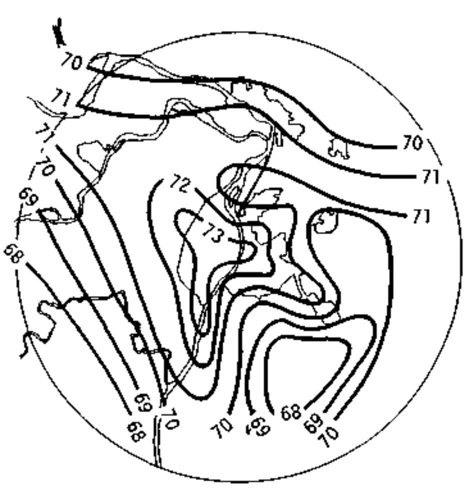
Figures I-3a-f depict the distribution of moisture about the study area as exemplified by mean dew point temperatures at 0700 and 1500 CDT for the three sky conditions. It may be seen that the warmer dew point temperatures are within the metropolitan area at sunrise, but that the air in the metropolitan area is deficient in moisture at the time of maximum temperature. In general, this moisture deficiency in the afternoon extends toward the west and the northeast from the city center. The bottomlands between the Mississippi and Missouri Rivers was a moisture source during the day. Comparison of the 0700 and 1500 CDT values for individual stations reveals



a. 0700 CDT b. 1500 CDT

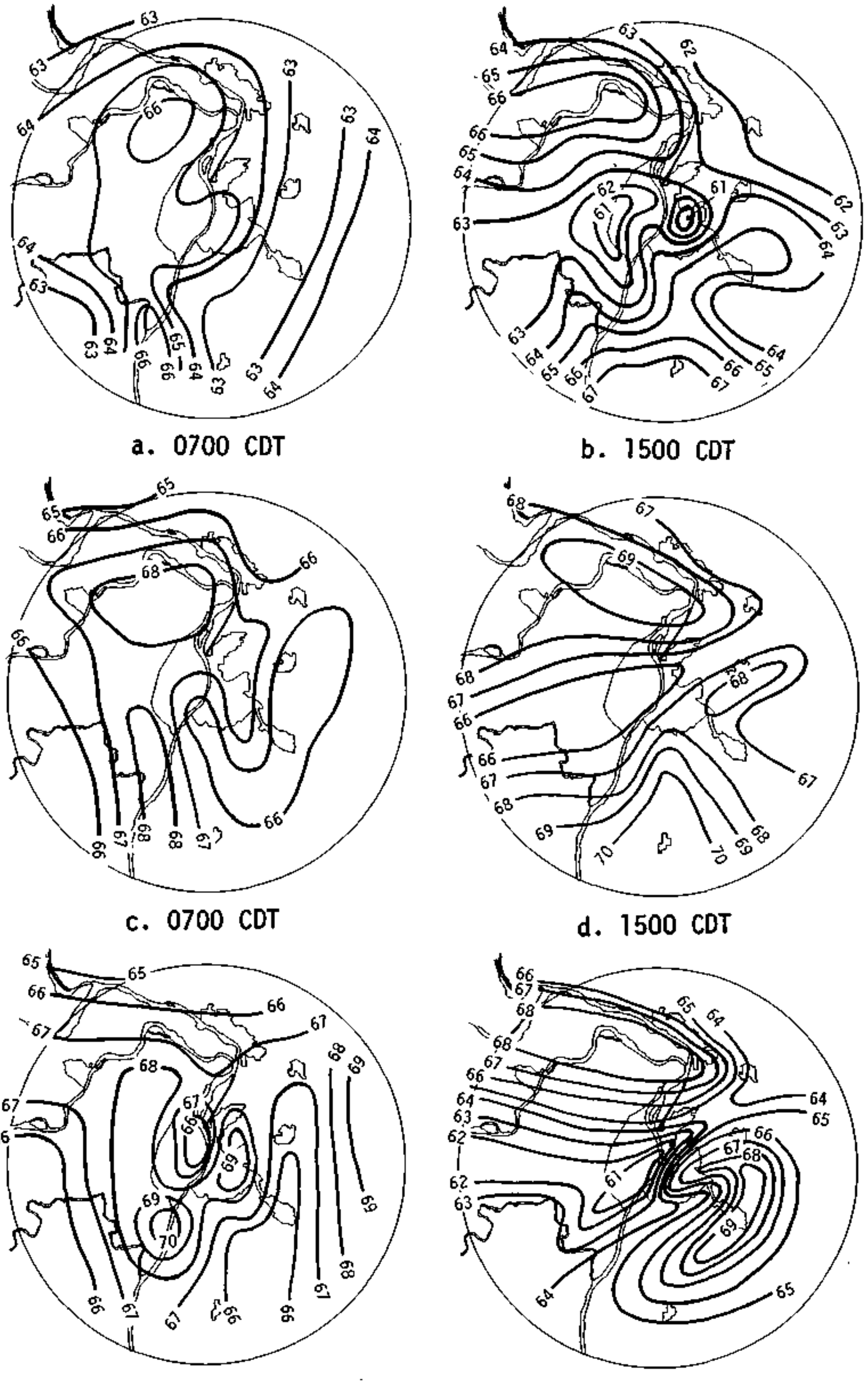


c. 0700 CDT d. 1500 CDT



e. 0700 CDT f. 1500 CDT

Figure I-2. Average air temperature at selected hours in summer 1973 for clear to partly cloudy (a, b), broken (c, d), and overcast (e, f)



a. 0700 CDT

b. 1500 CDT

c. 0700 CDT

d. 1500 CDT

e. 0700 CDT

f. 1500 CDT

Figure I-3. Average dew point temperature at selected hours in summer 197S for clear to partly cloudy (a, b), broken (c, d), and overcast (e, f) that the rural stations experienced a daily range of dew point temperature of only 2°-3°F with most of them showing an increase during the day. The urban stations experienced a daily range of 4°-5°F and a decrease during the day, thus steepening the moisture gradient between urban and rural areas during the day.

The charts of mean temperature generated by selecting particular hours with clear to partly cloudy skies at STL during August 1973 reveal the generation and partial dispersion of the urban heat anomaly. These charts comprise Figs. I-4a through I-4e. The sequence of charts begins with the 1100 CDT field of temperature when the transition between the nighttime and daytime patterns is occurring. The major cool areas were from Waterloo to Collinsville, the Ozark valleys southwest of the city, and on the bluffs above the Illinois River to the northwest. A warm area extended along the Mississippi River valley south of the city through the western portion of the city past STL to St. Charles.

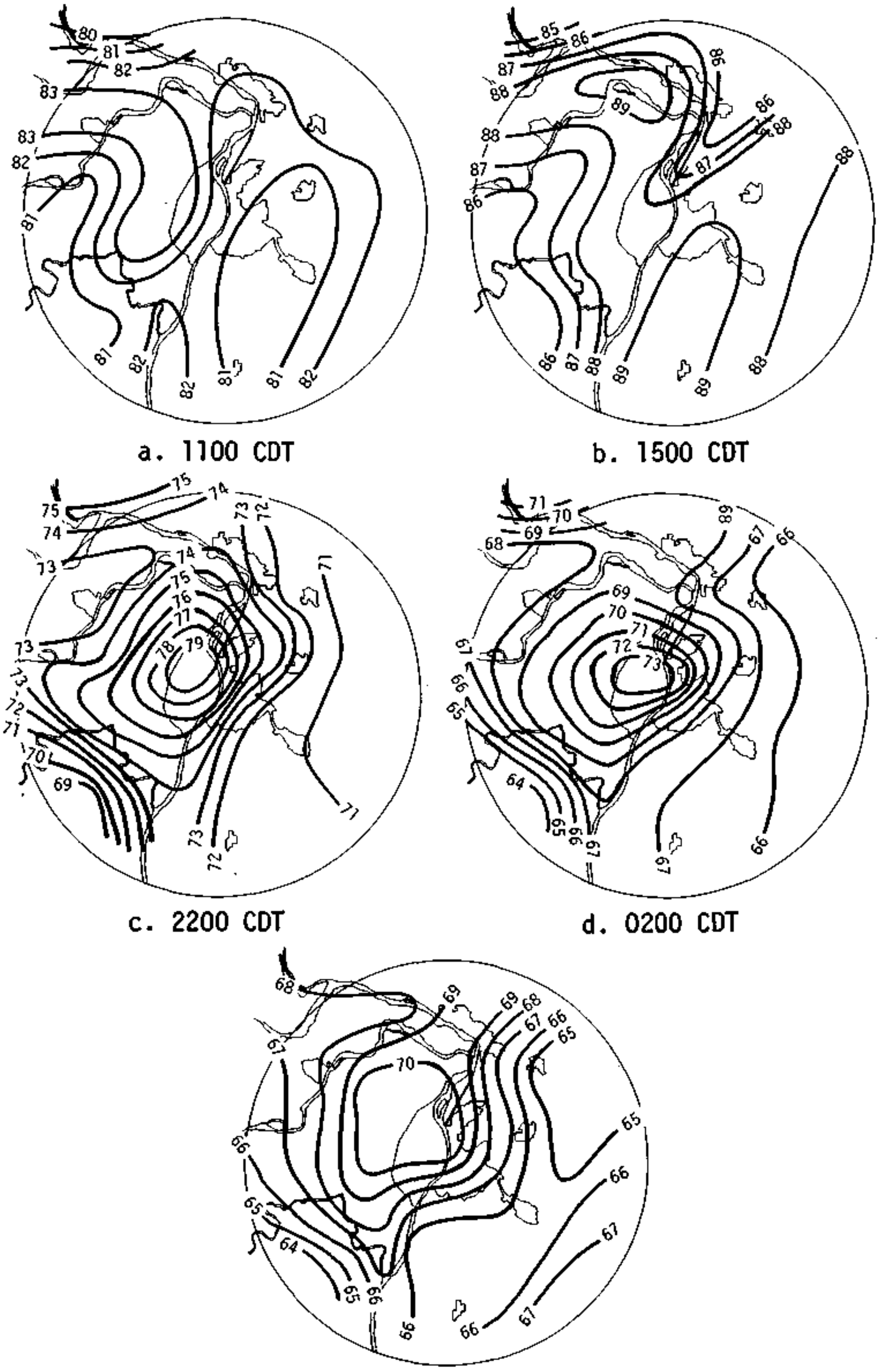
At 1500 CDT (Fig. I-4b) near the time of maximum temperatures at most of the sites, the warmest temperatures were from Waterloo to Collinsville where the coolest temperatures had existed just four hours earlier. A ridge of higher temperatures also extended from Waterloo through the city of St. Louis to another maximum in the floodplain between the Mississippi and Missouri Rivers. Cool areas were prominent from Roxanna to Granite City, the field headquarters at Pere Marquette, and in the Ozark valleys southwest of the city.

By 2200 CDT (Fig. I-4c), the urban heat anomaly was well established with the warmest area over St. Louis. Note that Pere Marquette (Site 00) on a bluff remained warmer than the lowlands between the rivers. This pattern continued through the rest of the night with the only variation being the changes in absolute temperature values (Fig. I-4d). However, by sunrise (Fig. I-4e) a warmer area east of Waterloo formed to isolate a cool area from Waterloo north-northeastward similar to Fig. I-4a.

Effect of Air Temperature-Dew Point Temperature Fields on Surface Precipitation

An investigation of the possible role of surface fields of temperature and dew point on the initiation and later intensification of surface precipitation was begun in 1974. The impetus for this investigation is provided by case study and numerical modeling results which indicated the possibility that urban effects at St. Louis may be strongly related to heat and moisture emanating at the surface. Several other investigators have noted the role of localized cool and warm regions in relation to preferred areas of thunderstorm development (Byers and Braham, 1949; Purdom and Gurka, 1974).

This is a partial study in that only the relationship between these fields and precipitation development is investigated in reference to raincell initiation and storm precipitation. Future studies will include the relationships between these fields and 1) corresponding raincell patterns, 2) echo development patterns, 3) raincell parameters in reference to whether cells developed and/or



a. 1100 CDT

b. 1500 CDT

c. 2200 CDT

d. 0200 CDT

e. 0700 CDT

Figure I-4. Mean air temperature under clear to partly cloudy skies at selected hours in August 197S passed through the localized hot and/or wet spots, and 3) cloud development areas. Air temperature and dew point data from 1971 were not used in this study because the density of reporting stations was much less than in 1972-1973.

Analytical Procedures

For every rain period (storm) during 1972 and 1973, the air and dew point temperature values for each hour of the 12-hour period prior to storm initiation on the network were mapped. For each hour, the areal mean temperatures and standard deviations were computed along with a "critical value", defined as the sum of the mean and standard deviation. The positive residual differences between the actual and critical values were then computed and accumulated for 1 hour, 6 hours, and 12 hours prior to storm occurrence. The differences were then accumulated for each month of the 2-summer periods and for each of four surface wind stratifications. The accumulated totals were designated as the air temperature and dew point "excesses" for the specified period prior to storm occurrence. These excesses represent the hot and/or wet spots at the surface during the period prior to storm occurrence.

These excesses were then compared to 1) raincell initiation areas, 2) storm precipitation occurring with various surface wind stratifications, 3) monthly precipitation, and 4) summer precipitation. To minimize the influence of localized exposure effects, excesses greater than an arbitrarily selected isoline are not shown on the temperature-dew point-precipitation (TDP) patterns. The areas of excess represent only *relatvely warm and moist regions.* Also, in the combined TDP patterns, a precipitation isoline was arbitrarily chosen in order to reduce complexity of three patterns on one map.

Results

Areas of raincell initiations were so frequent as to be significantly higher than elsewhere, at the 10, 5, and 1% levels, were superimposed on the patterns of accumulated temperature and dew point excesses ≥ 30 degrees. (These initiation areas were determined in the manner described in Section D. In 1972 (Fig. I-5), the more frequent initiation areas were in the general vicinity of the warm and moist regions south and east of the city. In 1973 (Fig. I-6) the most significant cell initiation area was located NW of St. Louis in the overlapping warm and moist regions. Most of the other initiation areas were in the moist region and along its eastern boundary. These two annual patterns do suggest a relationship between initiation of intense rain centers (cells) and quite moist and warm areas.

In Section C the prevailing wind directions at the surface level 3-6 hours prior to the onset of rain for each storm period during 1972 and 1973 were determined. The predominant airflow was from the SW during 1972 and from the SE in 1973. There was 77% of the storms in 1072 which had airflow from the SW and SE quadrants, and 81% of the storms had airflow from these two quadrants in 1973. The accumulated temperature and dew point excessess during the hour prior to precipitation for storms with SW and SE prevailing winds were compared to the subsequent precipitation.

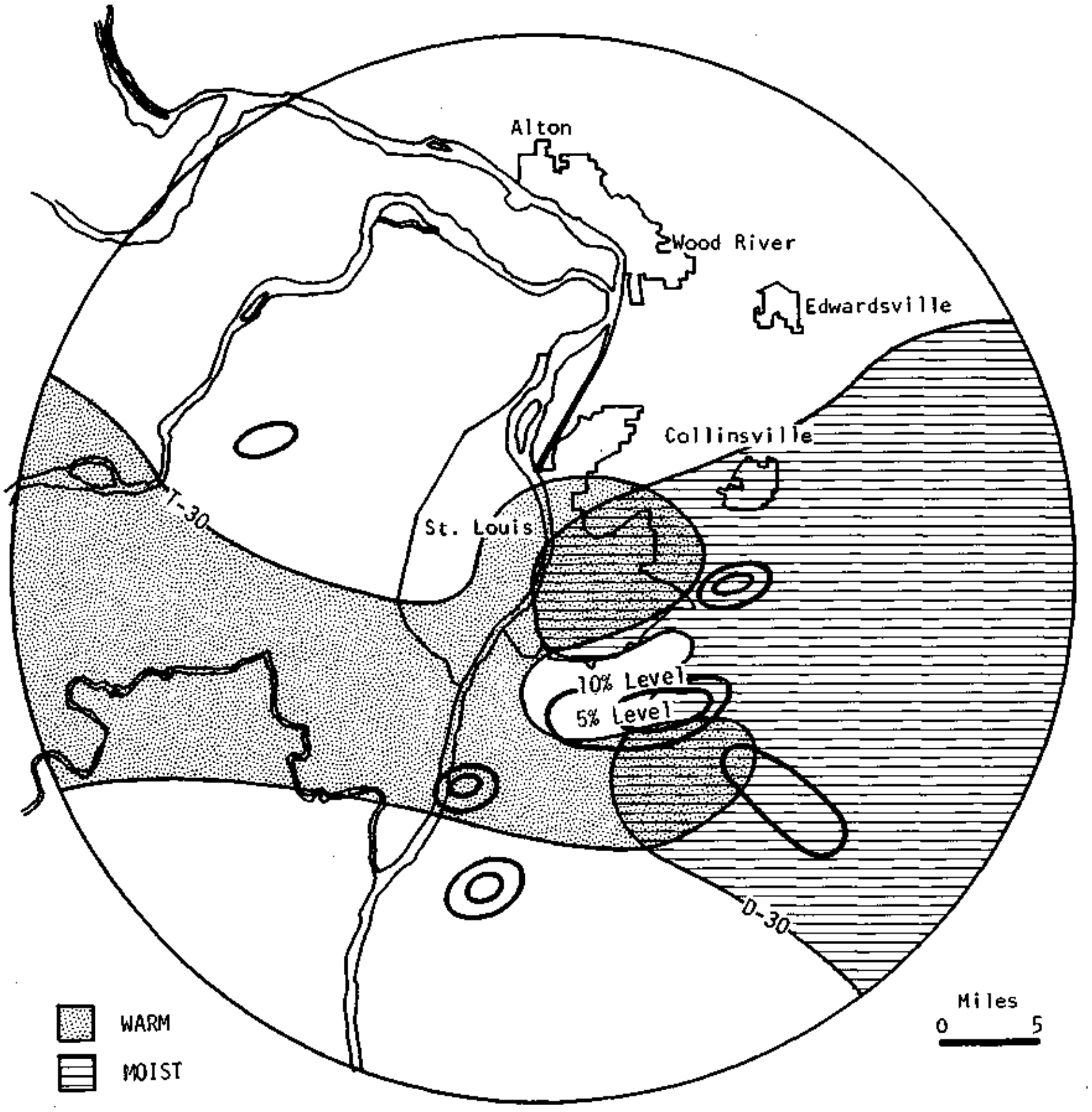


Figure I-5. Areas of raincell initiation significant at the 10 and 5% levels and the accumulated temperature and dew point excesses ≥ 30 degrees for summer 1972

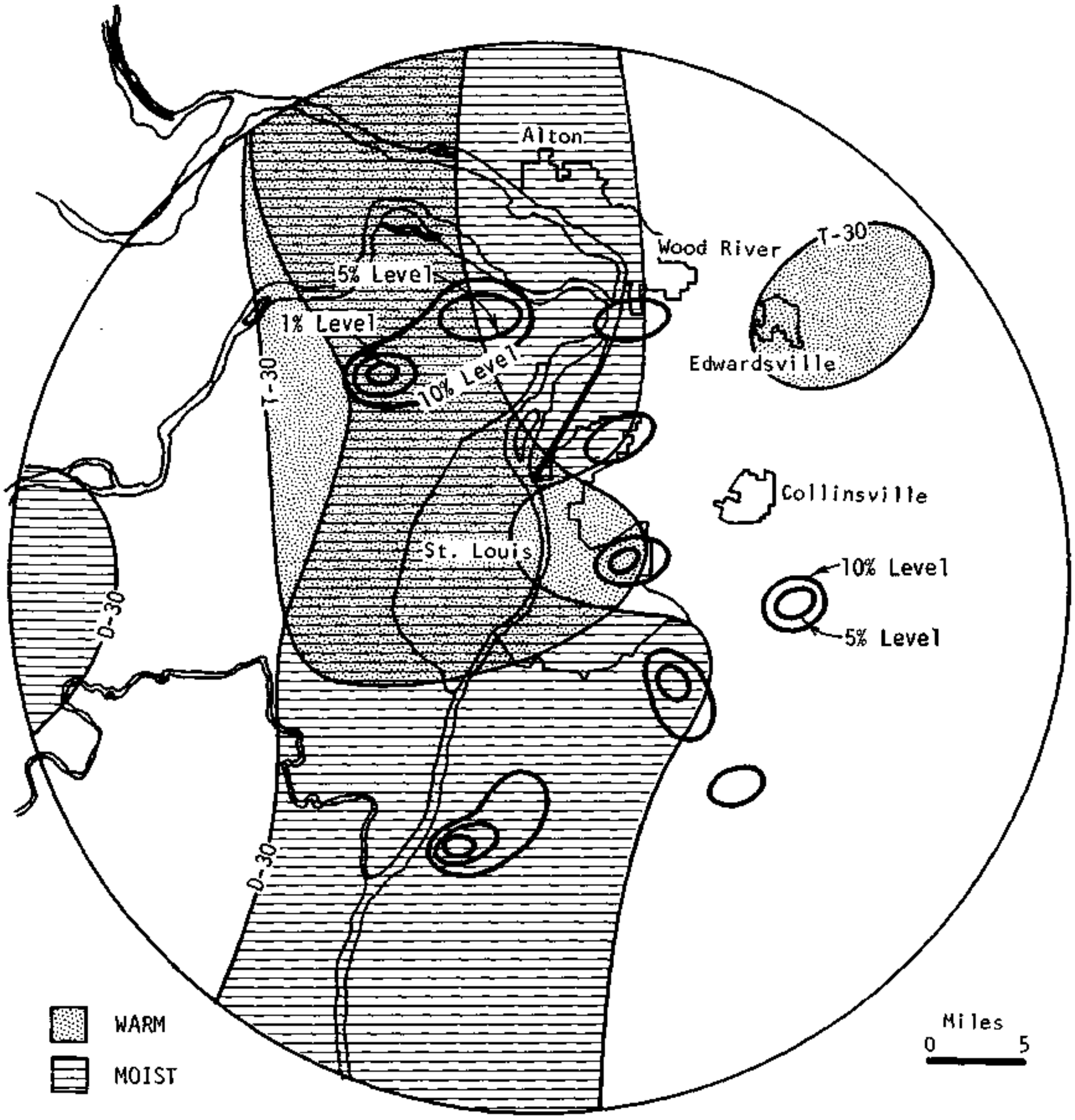


Figure I-6. Areas of raincell initiation significant at the 10 and 5% levels and the accumulated temperature and dew point excesses > 30 degrees for summer 1973

The total precipitation ≥ 6 inches and the accumulated temperature and moisture excesses ≥ 15 degrees during the hour prior to precipitation with prevailing winds from the SW in 1972 are shown on Fig. I-7. The greatest precipitation amounts occurred E-NE of the city and the 8-inch maximum at Collinsville occurred within a moist region and downwind of a overlapping warm and moist region. The most frequent raincell movement was towards the E-NE (Fig. I-7), and this area had an opportunity to frequently sample cells from the East St. Louis area. Also, this region of precipitation was downwind of the moist and warm region southeast of the city. There was a warm area to the west of St. Louis which was not associated with any precipitation maximum.

The direction of cell movements implies that some cells could have moved from the warm and moist region NE to the Edwardsville rainfall maximum. However, it was shown in a previous discussion (Section D) that the area of the Edwardsville high frequently samples cells which developed and/or passed through the Wood River area. Both the Edwardsville and Collinsville highs were within the general 1972 precipitation maximum (Fig. I-11). The Collinsville high was in a position to have frequently been effected by moisture and heat, whereas the Edwardsville high was not in a region of surface heat and moisture.

The total precipitation ≥ 4 inches and the accumulated temperature and moisture excessess ≥ 10 degrees with prevailing surface winds from the SE in 1972 are shown on Fig. I-8. There was a general area of precipitation within the moist region in the SE part of the network. There was also a maximum extending from NW of Collinsville eastward towards the edge of the network. This area of precipitation was partially within the wet and moist region immediately east of St. Louis. However, there was a warm region on the west side of the research circle and an overlapping moist and warm area at the bend in the Meramec River which were not associated with precipitation maxima.

There are certain features that are common to the pattern shown in Figs. I-7 and I-8. The warm and/or wet regions in the immediate St. Louis area were present with both southeast and southwest winds. The location of these areas shifted somewhat with wind direction, but certainly not in a predictable manner. Similarly, there was a general moist area in the eastern portion of the circle, and a warm area to the west of St. Louis. These moist and warm areas were also reflected in the overall pattern for 1972 (Fig. I-11). Thus, there is not good evidence to suggest that the surface airflow advected temperature and moisture from one region of the research circle to another.

Most of the precipitation occurred with southwest flow in 1972 and the precipitation was located east of the St. Louis-Granite City-Wood River areas. In this case, some of the heaviest precipitation occurred in the wet and warm regions. However, much of the warm and moist regions occurred outside of the heaviest precipitation and this suggests very slight correspondence. That is, the relationship between localized maxima, of precipitation with localized moist and warm regions was only slight. It was only the broad precipitation maxima which was related to the surface areas of moisture and this was also indicated by the data on Fig. I-11.

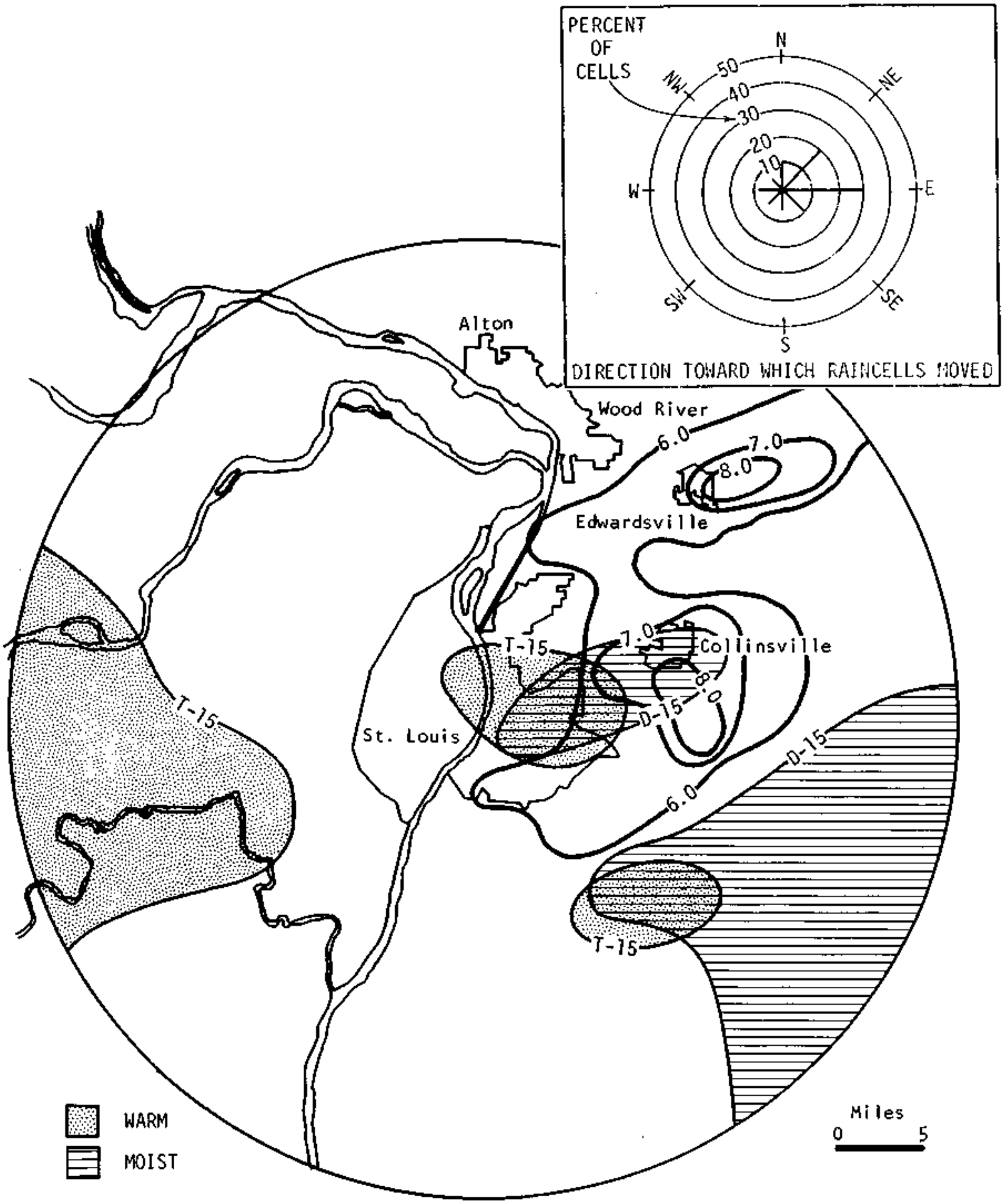


Figure I-7. Total precipitation ≥ 6 inches and the accumulated temperature and dew point excesses ≥ 15 degrees with prevailing surface winds from the SW during 1972 (30 storms)

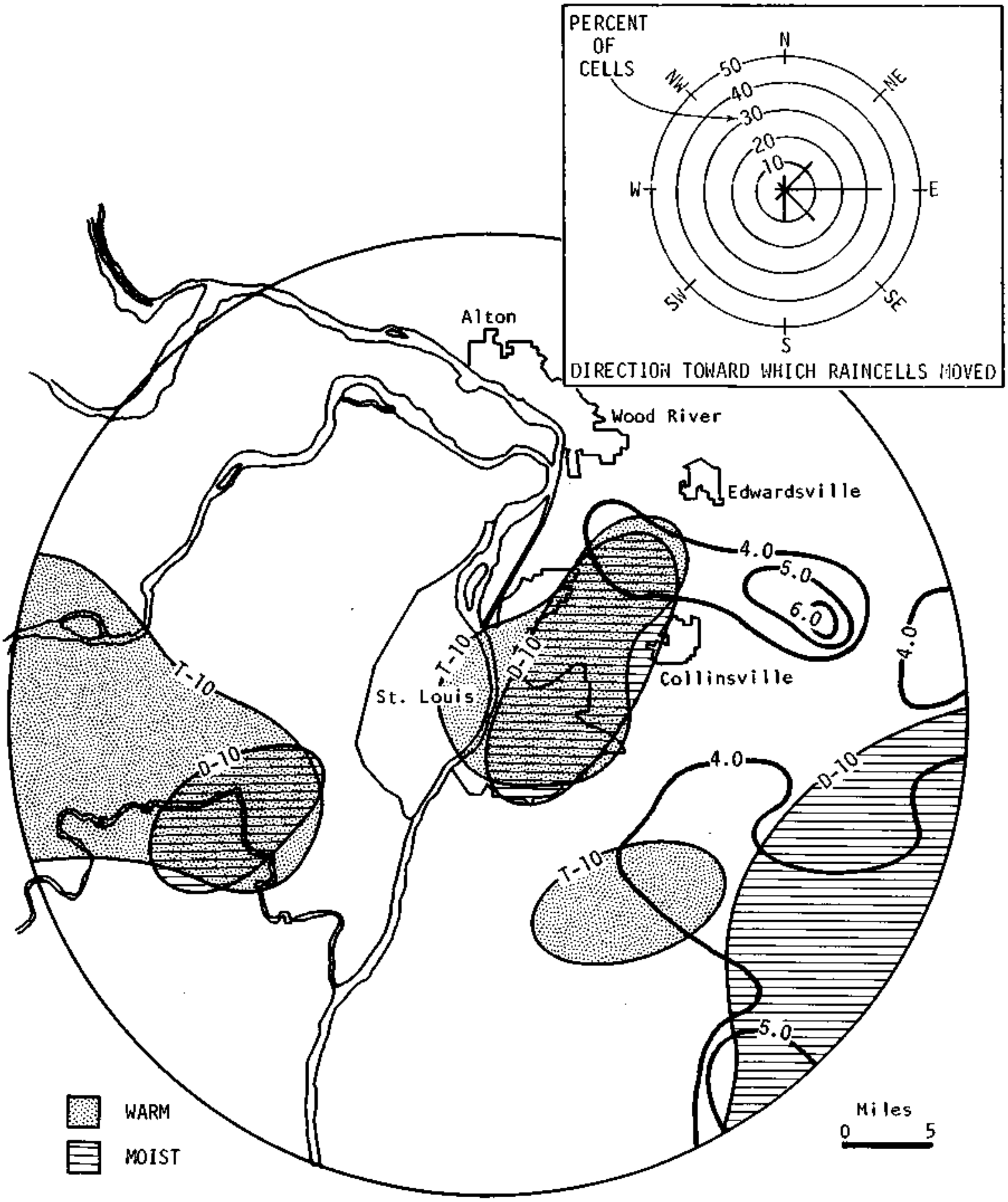


Figure I-8. Total precipitation ≥ 4 inches and the accumulated temperature and dew point excesses ≥ 10 degrees with prevailing surface winds from the SE during 1972 (20 storms)

The total precipitation ≥ 5 inches and the accumulated temperature and moisture excesses ≥ 10 degrees with prevailing winds from the SW in 1973 are shown on Fig. I-9. The precipitation maxima were located in and downwind of the warm and moist regions. The majority of cell movements were towards the E-SE and suggested movement of precipitation elements such that maximums would occur in or on the east side of the warm and moist regions.

The total precipitation ≥ 7 inches and the accumulated temperature and moisture excesses ≥ 20 degrees with prevailing winds for the SE in 1973 are shown on Fig. I-10. There was a general tongue of warm temperature which extended from the NW towards the SE. The greatest amount of precipitation occurred to the E-NE of the overlapping wet and warm region over St. Louis, which was in the same direction as the most frequent cell movement. There was another area of precipitation in the SE portion of the research circle which was in the direction of the most frequent cell movement from the moist region. The precipitation on the W edge of the circle was on the downwind side of the overlapping warm and moist regions, but was several miles away. The moist and warm areas shifted somewhat with the airflow during 1973 (i.e., the overlapping warm and moist areas in St. Louis shifted from east to west as the airflow shifted from SW to SE); however, they were generally located in the regions shown on Figs. I-11 and I-12 (the overall summer patterns). However, the warm and moist areas appeared in different localities during 1973 than in 1972. An exception was the warm and moist areas in the city of St. Louis which persisted both in 1972 and 1973.

The total storm precipitation ≥ 10 inches and the accumulated temperature and dew point excesses ≥ 30 degrees during the hour prior to precipitation for the overall summer period of 1972 are shown on Fig. I-11. This figure illustrates that the heaviest rainfall in 1972 was generally located in the vicinity of the moist surface conditions. The predominant airflow at the surface was from the southwest during 1972 and the most frequent cell movement was from the W and SW. Thus, the moist areas in 1972 were positioned such that they were often downwind of airflow from St. Louis and the moist Mississippi River valley. The heaviest rainfall was also located in the general downwind area, and the motion of individual raincells was such that they could have resulted from clouds which formed close to the city and the overlapping warm and moist regions. However, the overall 1972 summer pattern is largely reflected by the TDP pattern occurring with the SW airflow stratification (Fig. I-7).

The total precipitation - 10 inches and the accumulated temperature and moisture excesses ≥ 30 degrees for the summer of 1973 are shown on Fig. I-12. The heaviest precipitation was again generally in the area of moist surface conditions. The precipitation area stretching from the Missouri River bend SE into East St. Louis-Belleville was located in and immediately east of the moist and warm area of the research circle. The predominant airflow was from the SE and the moisture excess was located mostly in the Mississippi River valley and slightly to the west. The most frequent cell movement was again towards the E and NE.

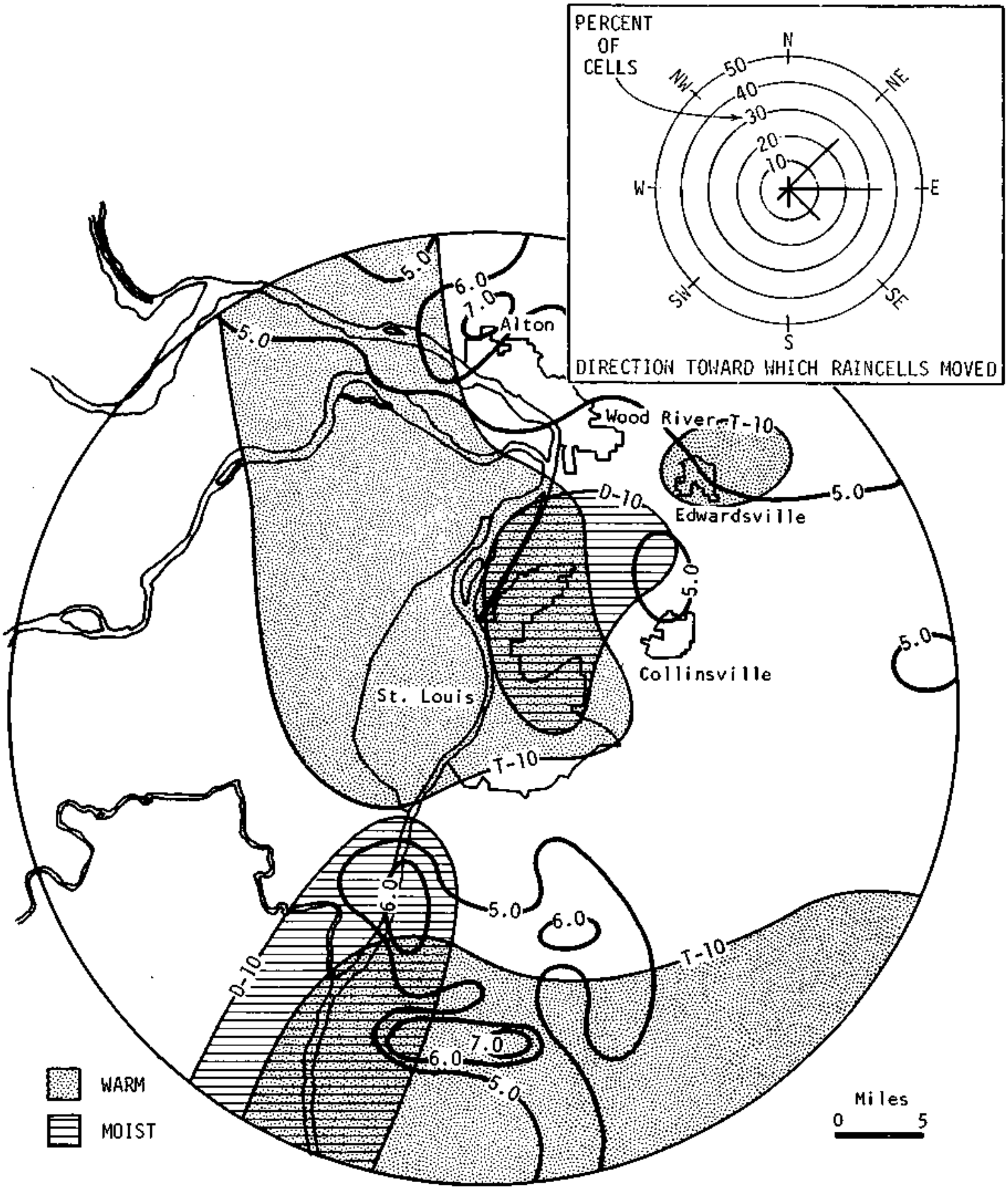


Figure I-9. Total precipitation ≥ 5 inches and the accumulated temperature and dew point excesses ≥ 10 degrees with prevailing surface winds from the SW during 1973 (23 storms)

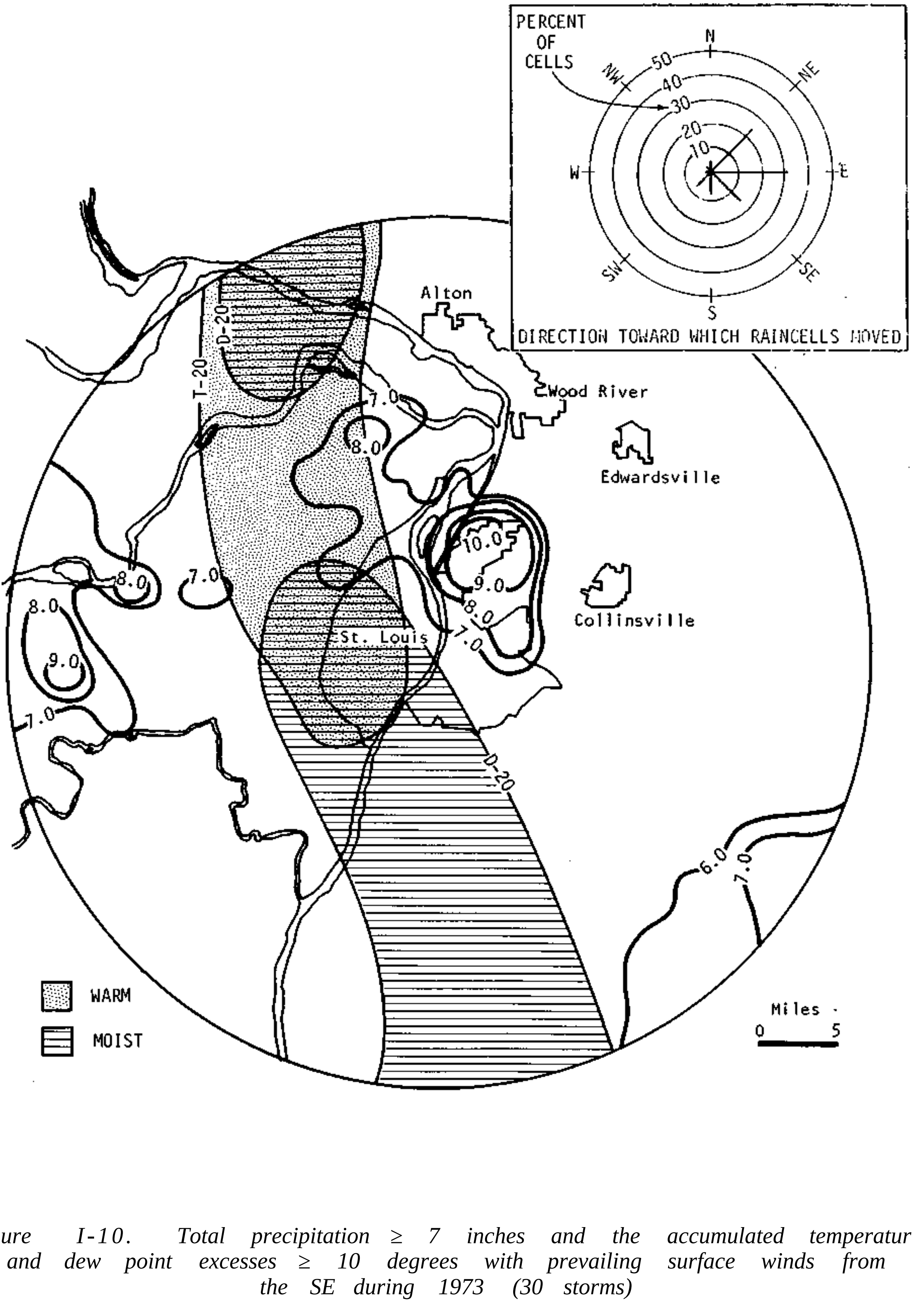


Figure I-10. Total precipitation ≥ 7 inches and the accumulated temperature and dew point excesses ≥ 10 degrees with prevailing surface winds from the SE during 1973 (30 storms)

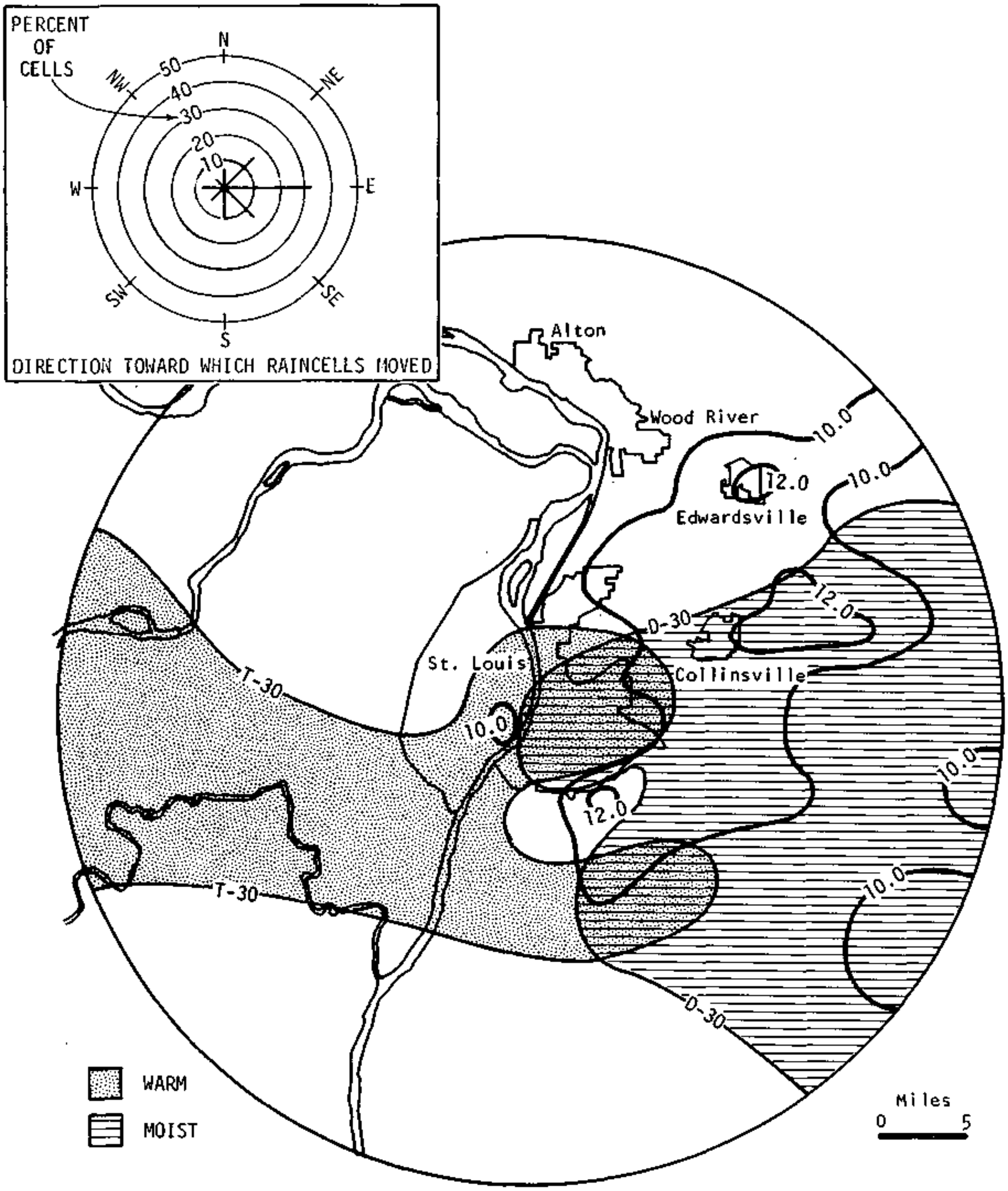


Figure I-11. Total storm precipitation ≥ 10 inches and the accumulated temperature and dew point excesses ≥ 30 degrees during the hour prior to precipitation for summer 1972

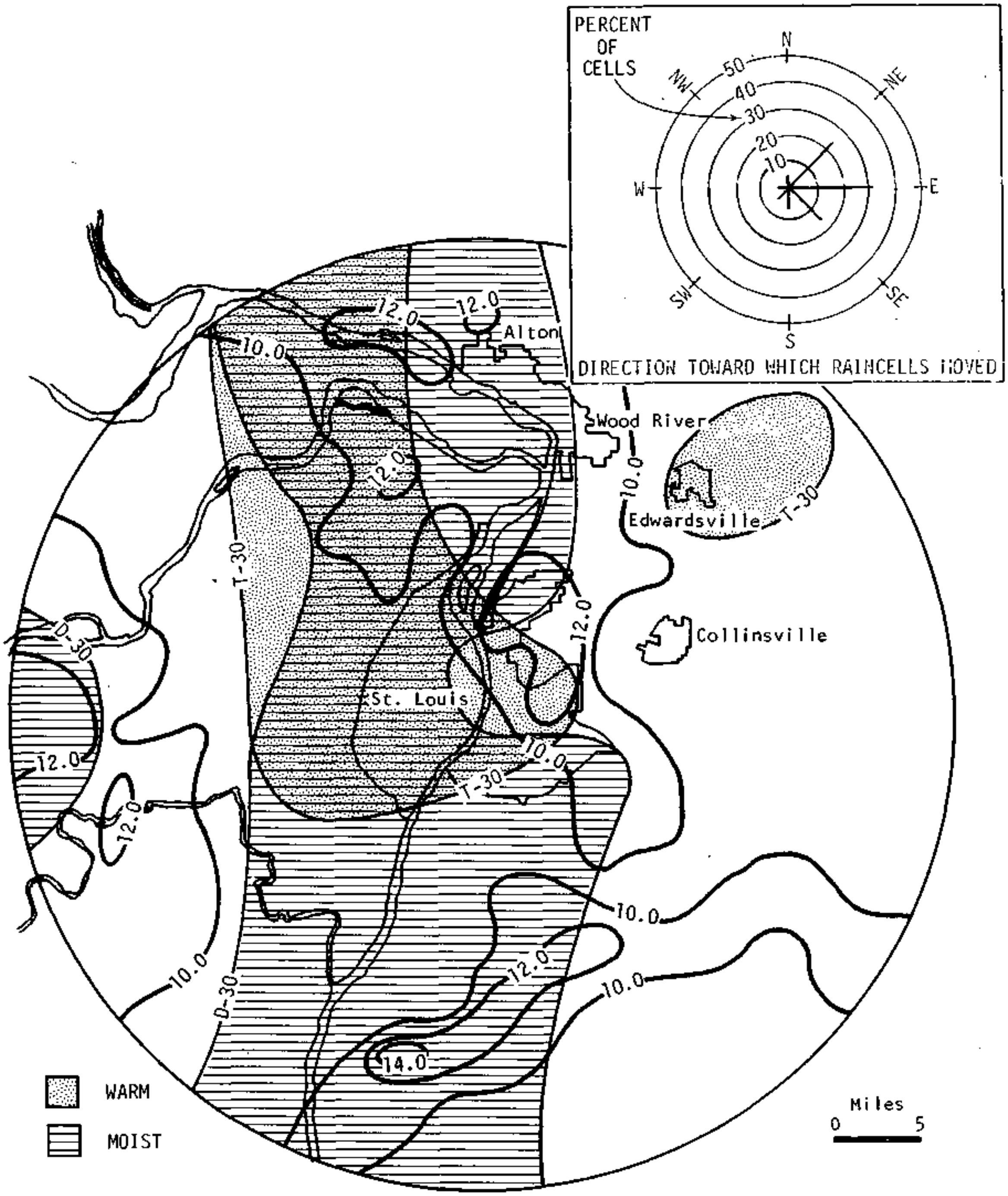


Figure I-12. Total storm precipitation ≥ 10 inches and the accumulated temperature and dew point excesses ≥ 30 degrees during the hour prior to precipitation for summer 1973

A comparison of 1972 and 1973 patterns indicate that the peaks in moisture and precipitation both shifted westward in 1973 from their positions in 1972. It is conceivable that the precipitation maximum may have moved westward in response to the shift in prior moisture conditions. Thus , surface patterns of moisture and heat may have played an important role in the development of precipitation. The warm area in the western part of the research circle during 1972 in the absence of precipitation suggests that surface heat alone is not sufficient for the development of precipitation.

The TDP patterns for the periods 0-6 and 0-12 hours prior to the onset of precipitation during the summers of 1972 and 1973 were also investigated. In general, there was less correspondence in these periods than for the hour immediately prior to precipitation.

The TDP patterns for the individual months during the summers of 1971 and 1972 were analyzed. During 1972, the greatest correspondence between surface conditions and the precipitation pattern occurred during the month of August. The correspondence during this month was between precipitation and the moisture pattern. Small localized maximums of precipitation occurred within the general precipitation area and immediately east of areas of maximum moisture and heat. There was a lack of precipitation in warm regions in the western and northwestern portions of the research circle.

During 1973, there was some correspondence of precipitation with surface conditions in all months. The greatest correspondence occurred in reference to the moisture pattern and/or areas of overlapping moisture and temperature excess during the months of July and August.

There appears to be a general correspondence between the prior moisture fields and the subsequent development of precipitation. However, the patterns illustrate there is not a close relationship. It is hard to predict the positions of the warm and moist areas on the basis of surface airflow. Thus, other processes (microphysical, etc.) must also play an important role in determining the cause of the observed precipitation anomalies.

Surface Winds in 1973

The surface winds recorded at 8 locales during June, July, and August 1973 were stratified by frequencies of direction. These were based on the recordings that were reduced by averaging the wind speed and direction during the 10-minute interval preceding each clock hour. These "hourly readings" of direction were then separated into 16 points of the compass with the number in each direction divided by the total number of observations to determine the percentage for each direction. The siting and the instruments were described by Jones (1973b). Six sites are Water Survey instruments, one is operated by the National Weather Service (Lambert Field), and the other is a privately-owned instrument (Freeburg).

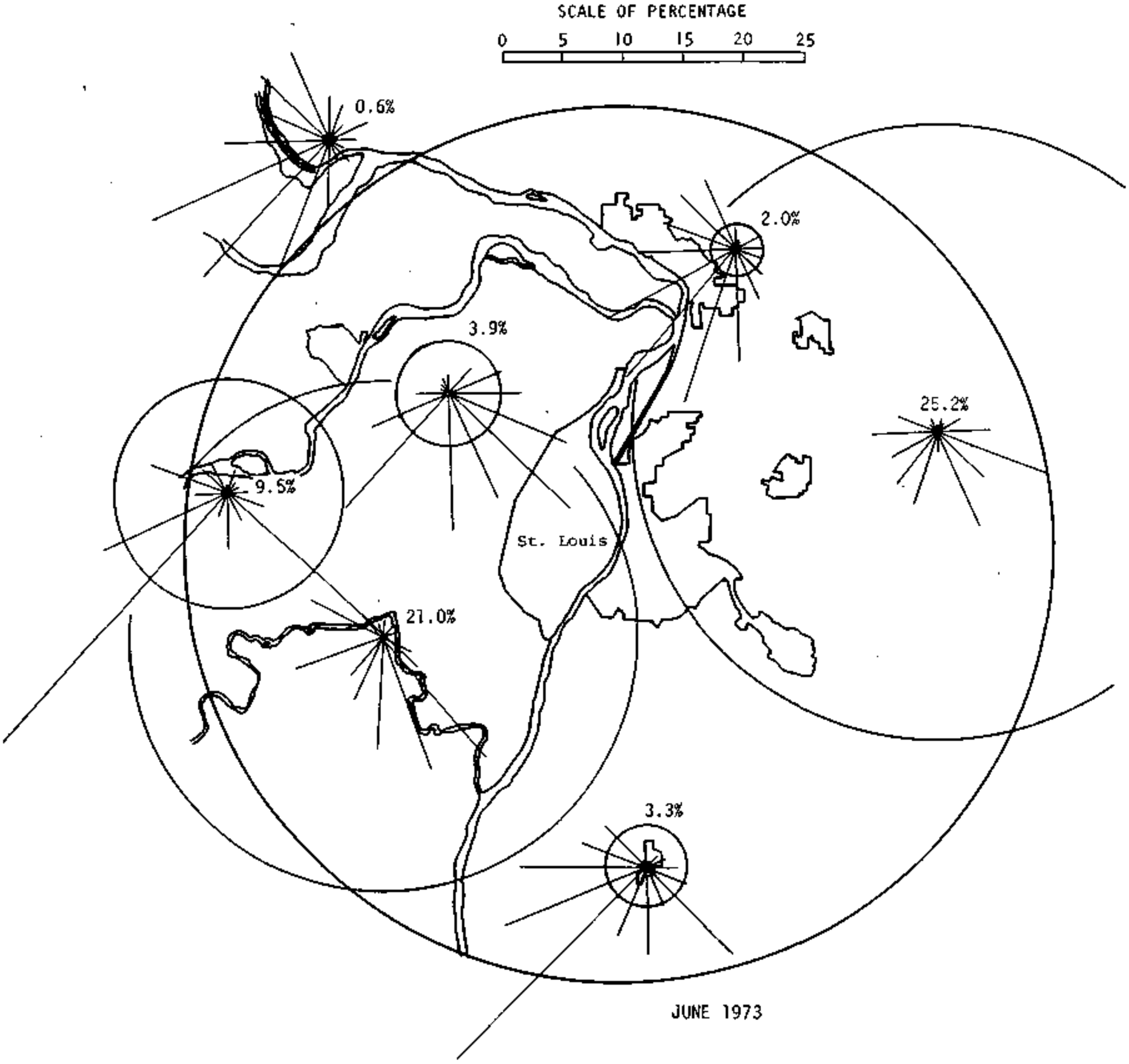


Figure I-13. Wind roses for June 1973

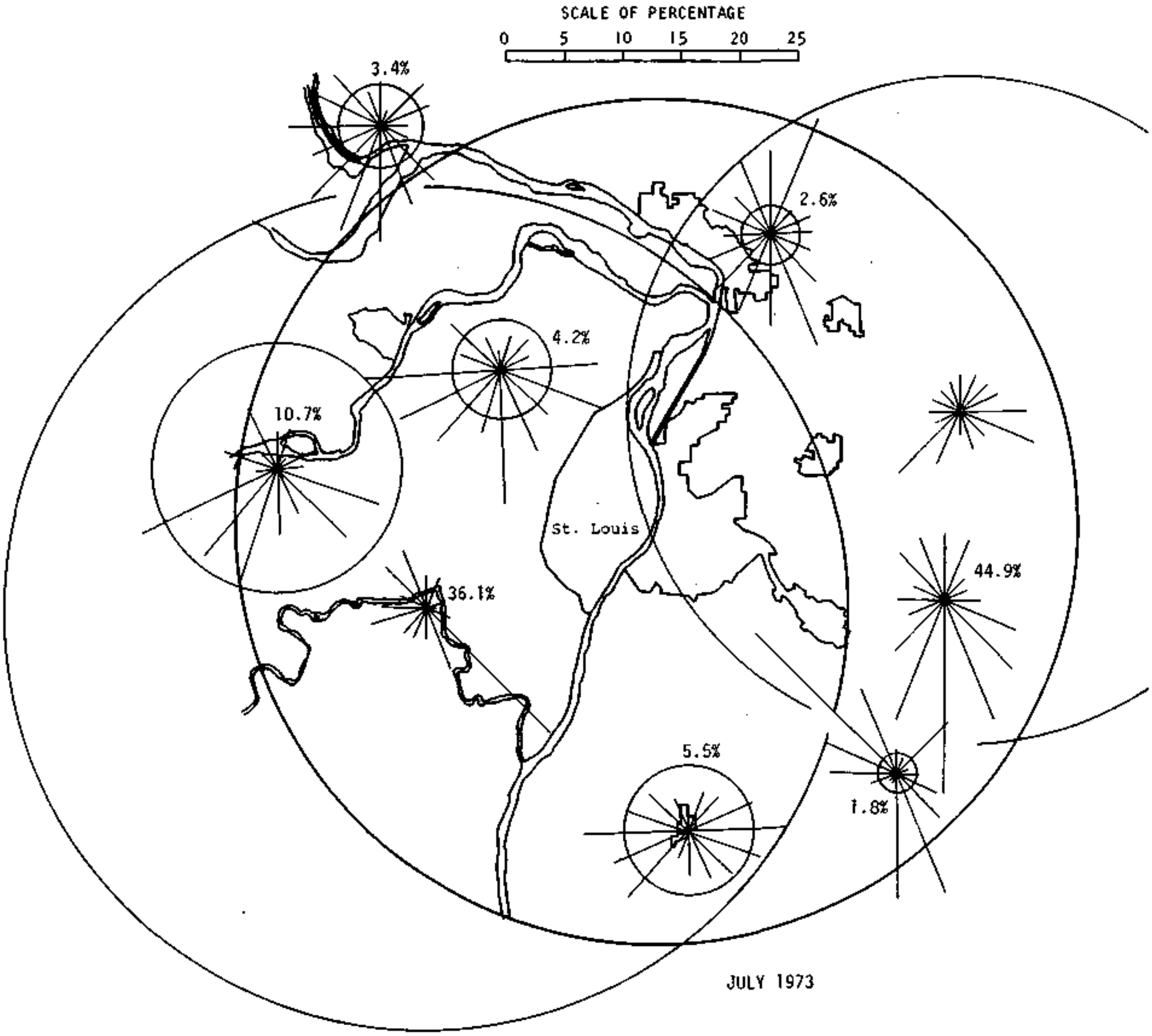


Figure I-14. Wind roses for July 1973

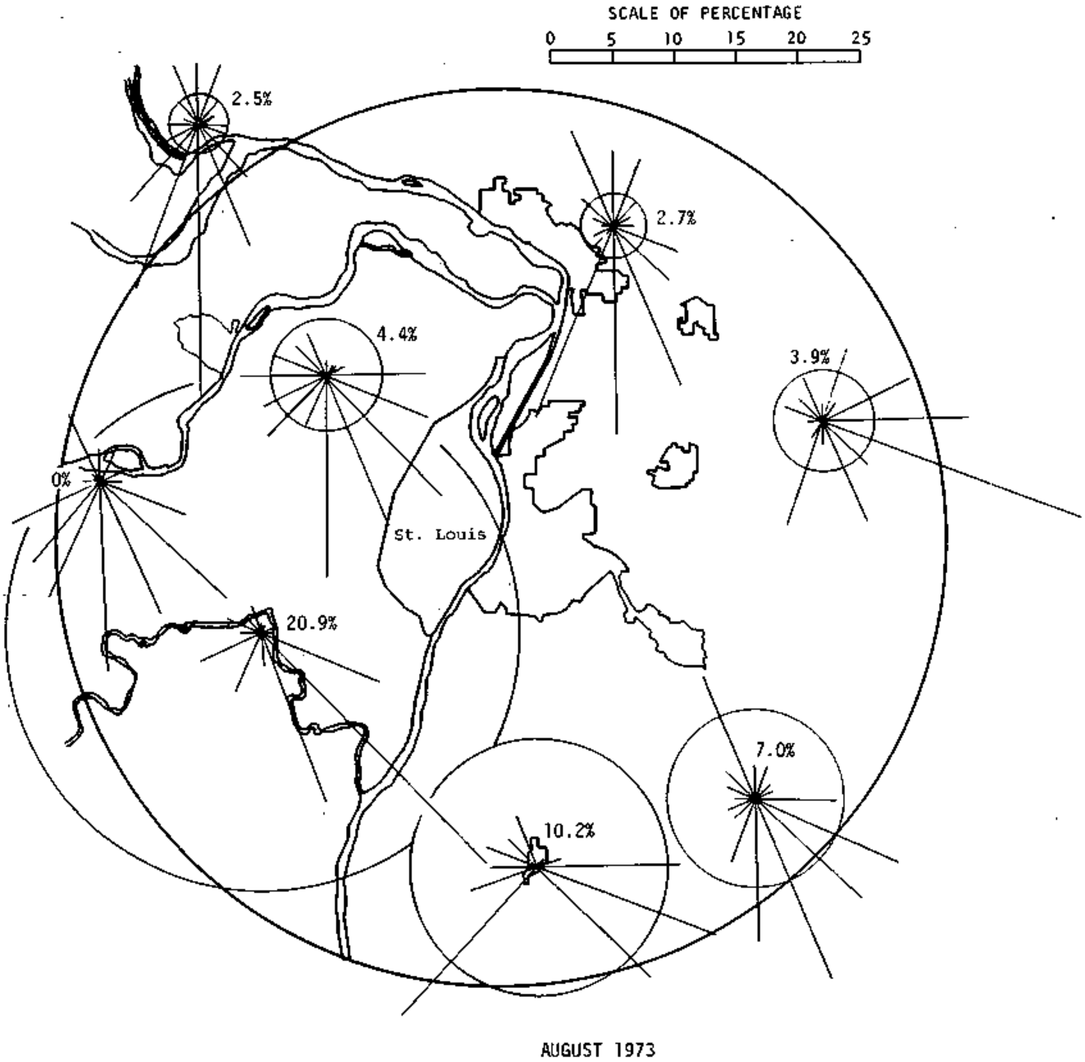


Figure I-15. Wind roses for August 1973

Figure I-13 shows the wind roses (without speeds) for June 1973. The predominant wind direction was southwesterly with a secondary maximum of southeasterly winds indicated at SUS, Weiss, STL, and Waterloo. The July wind roses in Fig. I-14 show a predominance of southerly winds. However, Freeburg also had a relatively high percentage of NW winds and ALN had NNE directions as often as SSE. Southeasterly winds were most common in August (Fig. I-15). Northerly winds were relatively rare except at Freeburg and ALN. The frequency of 180-degree winds at Nagel may be due to a site peculiarity. Other site peculiarities likely caused the higher frequency of SE winds at SUS, which is in the Missouri River valley.

Although site peculiarities affect the 1973 results, certain observations can be made. First, in any month there were systematic regional differences in wind direction around St. Louis. In June, the northernmost and southernmost stations had a preponderance of S and SW winds, whereas those stations west and east of St. Louis had SE as a preferred direction. In August, stations in the southern half of the research circle had SSE, SE, and ESE as preferred directions, but the three northern stations had southerly predominating winds. These systematic regional differences on a monthly scale observed in 1973 were similar to results obtained for summer 1972.

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J. BOUNDARY LAYER PROGRAM

Bernice Ackerman and Herbert Appleman

Introduction

During the first two years of METROMEX (1971 and 1972), the boundary-layer program was designed around field experiments during which observations were made at locations and times which best served narrowly-defined goals. In 1973, the program stressed routine daily observations from a fixed network of stations. The objectives were:

1) To depict the summertime wind field in the planetary boundary layer over St. Louis and its rural surrounding.
2) To determine the thermodynamic structure in the lower and mid-troposphere over the city and its rural surroundings.
3) To provide supporting wind and thermodynamic data during periods of specialized studies.

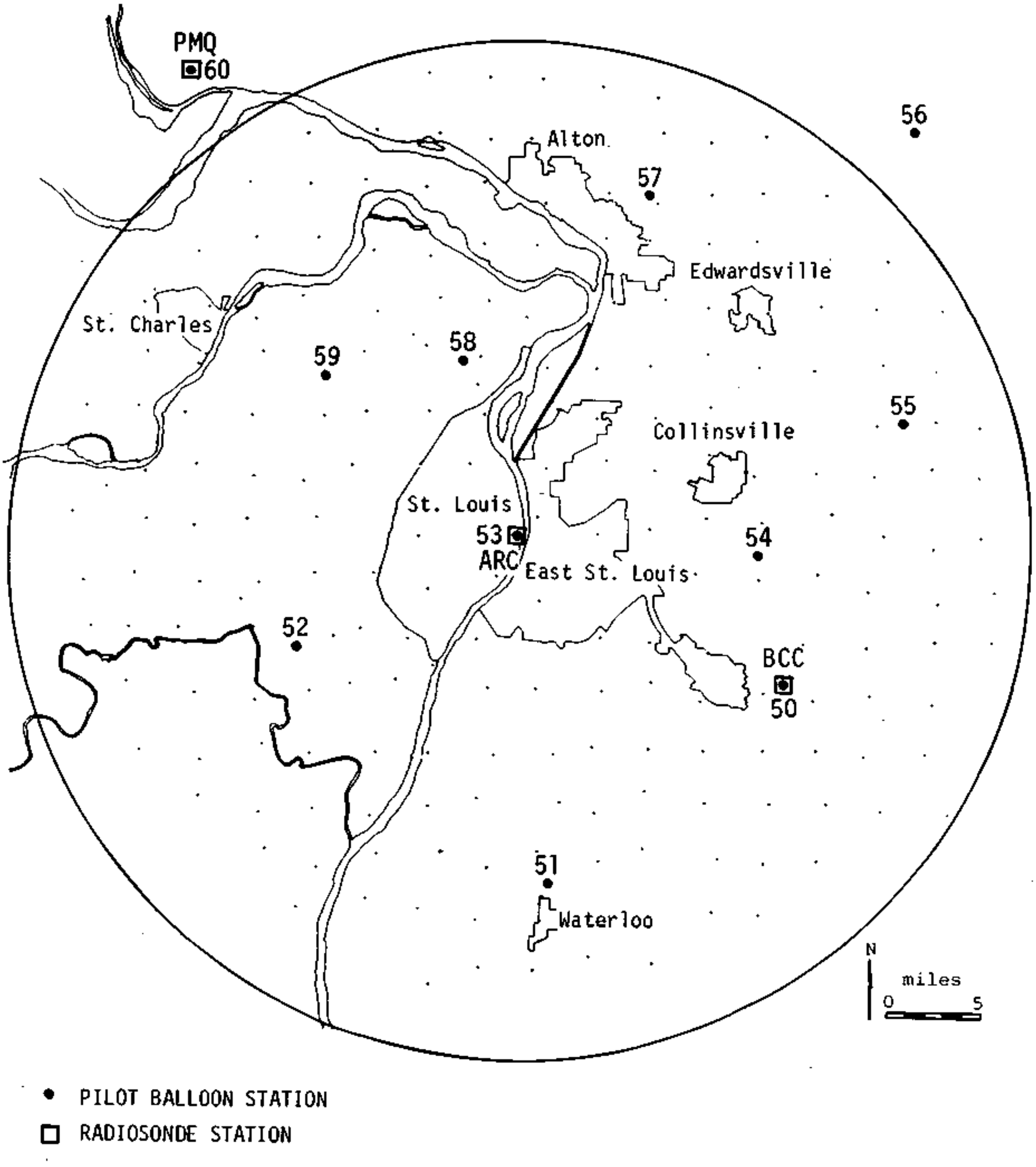
Both the wind and thermodynamic structure are important in determining the dispersion of the city's effluent. However, they may prove especially important in attacking a key problem of inadvertent weather modification by lending insight into the causes for the existence of preferential areas around the city for the initiation and/or enhancement of rainfall and severe weather.

Field Operations

The 1973 field observations were carried out from 11 July to 23 August. The wind measurements were made from 11 stations in and around the city Fig. J-1. These were sited so as to provide coverage for the whole metropolitan area and the country-side to the east, the location of the precipitation anomaly (see map, Fig. J-l). The terrain and land use varied from site to site, both in the city and in the country.

Radiosonde measurements were made from three stations, roughly on a NW-SE line across the city (Fig. J-l). The northwest site was at Base Headquarters in Pere Marquette State Park (PMQ, Site 60), a wooded area well away from any significant urbanized complex. The central position was in the city, at the Arch (ARC, Site 53). The station at the southeast end of the line was an essentially rural site on the grounds of the Belleville Community College, Illinois (BCC, Site 50).

Wind measurements to about 3000 m were obtained primarily by single theodolite tracking of 30-gram pilot balloons. Standard inflation rates were used and angular readings were tape-recorded at 30-second intervals. The thermodynamic measurements were made with 403 MC radiosonde equipment at



Figuve J-1. Map of the METROMEX research circle showing location of pibal and radiosonde stations in 1973

Sites 50 and 53 and with a GMD-1 radio tracker at Site 60. The radiosonde balloons were tracked by theodolites at the first two locations and by radio signal at the third, providing wind measurements based on computed balloon heights rather than on assumed ascent rates. Over-inflated 100-gm balloons were employed for routine observations and 600-gm balloons for launches made for special purposes. The 100-gm balloons rose at rates of 3 to 4 mps and usually reached 500 mb or higher.

Routine observations were made from all sites six times weekly, Monday through Saturday. Pilot balloons were launched six times daily from the pibal sites and four times daily from the radiosonde sites. The remaining wind measurements at the radiosonde sites were provided by the tracks of the radiosonde balloons. The launch schedule, shown in Table J-1, provided meso-synoptic coverage of midday winds at nominal times of 1200, 1400, and 1600 CDT. Paired launches were made at these times in order to provide, through averaging, the opportunity to minimize errors associated with the assumption of constant balloon ascent rate and to handle problems of non-representativeness associated with the unsteadiness of the wind.

Table J-l. Pibal/Radiosonde Schedule, 1973

	Launch Times, CDT
Pibal Sites	1130, 1200, 1330, 1400, 1530, 1600
Radiosonde Sites, pibals	1130, 1200, 1530, 1600
Radiosonde Sites, radiosondes*	0700, 1330

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* Wind measurement by theodolite tracking of radiosonde balloon at Belleville and the Arch (Sites 50 and 53, respectively) and by radio tracking at Pere Marquette (Site 60).

Additional observations were made during special periods of convective weather. The launch schedule and locations varied to suit the particular situation. On six occasions the entire network was involved; on these days radiosondes were released hourly and pibals every 30 minutes. Twenty-five hundred wind profiles and 275 thermodynamic soundings were obtained during the 6-week observational period.

Data Processing

The data reduction procedures utilize computer processing wherever possible. The winds are calculated for 30-second layers (approximately 100 m) and 60-second (approximately 200 m) overlapping layers by standard trigonometric techniques.

For single theodolite measurements, the heights assumed at each observation time are those used in practice by the National Weather Service; computed heights are used with radiosonde tracking data. The radiosonde record is routinely evaluated by determining humidity and temperature ordinates at every pressure contact. These are then processed by computer to provide temperature, humidity, and a variety of derived thermodynamic quantities. Both the wind and thermodynamic data are carefully screened for errors and corrections are made when necessary. All edited data are archived on magnetic tape.

The initial studies are concentrating on determination of the pre-rain kinematic and thermodynamic conditions over the region. To date, the wind and radiosonde data from 11 rain days (about 65% of all rain days) have been processed. Presented below is a summary of the average thermodynamic and kinematic characteristics of this partial sample. Two non-rain days have also been examined to provide an opportunity to compare disturbed and fair weather conditions.

The general weather characteristics of the 13 days are given in Table J-2. One day (August 9) has been omitted from most analyses because of the early onset of rain.

Thermodynamic Characteristics

The purpose of this portion of the study was to compare the thermodynamic characteristics at the three radiosonde sites on rain days. Generally the rain occurred in the afternoon or evening, so emphasis has been placed on the regularly scheduled 1300 CDT sounding. Although light rain showers fell before or during the midday sounding on 24 and 25 July, they were sufficiently distant from the radiosonde stations so that the soundings probably were not affected by local shower effects.

Because of the limited sample and occasionally missing data, it has been necessary to do a somewhat "piecemeal" analysis. The urban and rural measurements have been compared in two ways: (a) average of all 1330 CDT releases regardless of wind direction, for which data are available at all three stations (9 days), and (b) separate comparisons between the urban site and a single rural site for cases where, for the lower 2 km, the upwind fetch into the latter was over open country. For the latter analysis eight days were available for ARC-BCC comparisons, and seven days for ARC-PMQ comparisons; in these subsets the rural data are referred to as "unaffected".

The surface temperature and humidity measurement was occasionally suspect. For the sake of uniformity the computations were based entirely on radiosonde measurements. The height of the first contact above the ground averaged about 40 to 50 m. When necessary the lower portions of the temperature and humidity curves were extrapolated back to the surface.

Table J-2. Some General Weather Characteristics of the Data Sample

Date	General Synoptic Conditions	Boundary Layer Winds	Rain
7/14	Cold front, 150 mi SE of the network. Some over-running.	WNW backing to west, WSW aloft.	Post cold frontal showers starting 1455 CDT.
7/20	Stationary front, 150 mi N of the network.	SW	Light showers from a dissipating squall area starting about 1345.
7/23	Stationary front, NE 200 mi. Squall line moving in from about 70 mi west.	SSE veering to SSW	Pre-squall line showers starting about 1445, with heavy showers following.
7/24	Warm front, 250 mi NE. Squall line 125 mi NW moved S but did not cross network.	WSW veering to W	Two shower areas in E and SW parts of network, 1150-1450 CDT.
7/25	Cold front about 100 m west, moving eastward, passing STL about 2100 CDT.	SSW veering to W	Very light air mass showers from 1130 to 1300 CDT.
7/27	Stationary front 50 mi N of network.	WSW veering to NW	Showers starting about 2115.
7/30	N-S oriented warm front, 40 mi WSW.	S to SW	Squall line showers starting in NW at 1430 CDT.
8/ 7	West side of subtropical high with weak 500 mb ridge.	SSW	No rain in network.
8/ 8	Flat pressure gradient NW side of subtropical high.	SSW to SW	No rain in network.
8/ 9	Cold front 225 mi NW. Prefrontal rain area passes through network in morning.	SW veering to W	Stratiform rain showers 0725-1145. Squall line rain 1700-2100.
8/10	Warm front 100 mi NNE.	Light and variable	Squall area showers starting 1420 CDT.
8/12	Cold front 75 mi N; pre-frontal squall line in afternoon	SSE to SSW	Squall line shower starting 1445 CDT.
8/13	Cold front 150 mi WNW. Prefrontal squall line.	S (very light) to WSW	Squall line shower started about 1445 CDT.

Mean Profiles. The average temperature and dewpoint profiles for ARC and the unaffected rural site are shown in Fig. J-2a and b. It should be noted that these averages contain five days in common. The average ARC temperature profiles for the two sets were nearly identical and the average dewpoint curves were similar in shape and differed by about 1°C. Thus, the conditions on the unmatched days were not grossly different from those on the five common days, at least in the city.

The urban (ARC) temperatures averaged 1° to 2°C higher than those at the unaffected rural locations, through at least the first 1 to 2 km. The differences between temperature profiles and the depth of this lower relatively, warm layer at the Arch were greater between the ARC and BCC than between the ARC and PMQ. Above a layer of nearly equal temperatures from 2 to 3 km, the urban air was again slightly warmer (1/2 to 1°C) than at the upwind rural locations. These differences at 5 km (nearly 500 mb), small as they are, are not only significant but even somewhat surprising, considering the short distances involved.

The urban dewpoints were uniformly lower than those at the unaffected rural sites, which indicates lower moisture contents, and in concert with the generally warmer temperatures, lower relative humidities. The consistently high average moisture at Pere Marquette up to 5 km appears suspicious. It was not due to one or two anomalous cases in this small sample - the 4- to 5-km dewpoints at PMQ were greater than at the Arch on five of the seven days. Although comparison of 500-mb dewpoints for 25 simultaneous soundings does not suggest any consistent instrument bias, the possibility of measurement error cannot be ruled out. Thus, the PMQ values of all thermodynamic parameters involving moisture should be accepted with reservations.

The average temperature and dewpoint curves for the two non-rain days are shown in Fig. J-3 for comparison with pre-rain conditions. The stable layer at about 2400 m at PMQ was a true feature on both days; it was a weak feature at ARC, occurring at slightly different heights on the two days. As on the rain days, the ARC temperatures were roughly 1°C higher than at PMQ in the lower 2 km. The moisture at ARC was also considerably less than at PMQ in the lowest km but was almost identical at the two stations in the second km. As on the rain days, the PMQ dewpoint was about 5°C greater than that at ARC in the 3 to 5 km layer. Although not relevant to the present discussion it is interesting to note evidence of the dry air aloft,a rather sharp slope to the base of the dry air aloft. The difference in the heights of PMQ and the ARC (about 300 m) agreed with that observed on two similar days in 1972.

Stability Indices. A number of stability indices were computed from the 1330 soundings: the Cross Totals Index (CTI), Vertical Totals Index (VTI), Total Totals Index (TTI), Showalter Stability Index (SSI), and the Lifted Index (LI). These are defined and computational methods outlined at the end of this section. Only the VTI is independent of the moisture in the column. Values quoted for all others at PMQ should be considered tentative because of the possibility of measurement error. Values of 18, 26, and 44 or greater for CTI, VTI, and TTI, respectively, are considered indicative of thunderstorms; an SSI

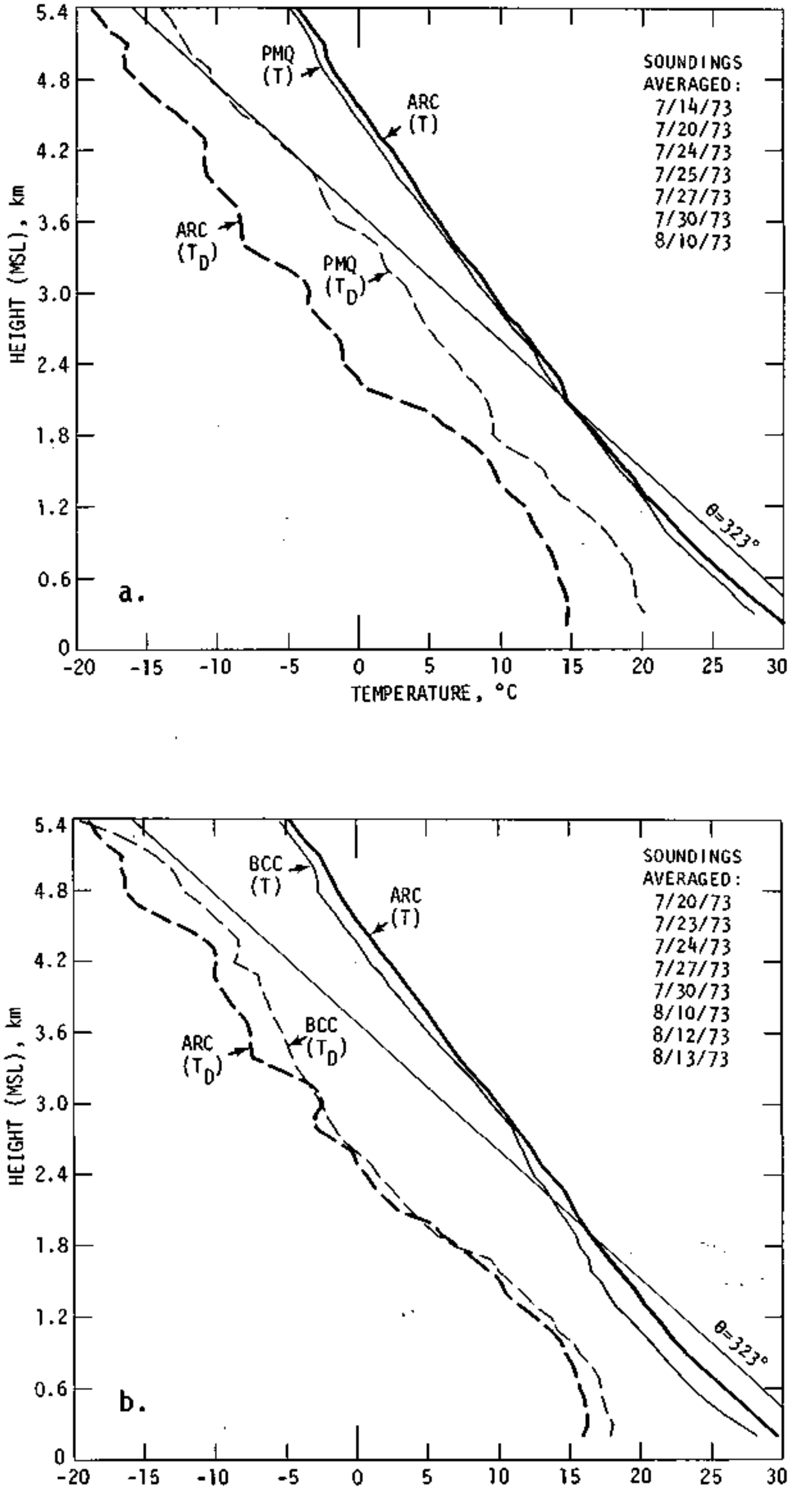


Figure J-2. Average pre-rain temperature and dew point profiles for approximately 1S30 CDT at the Arch and the unaffected rural station (a) for days when Pere Marquette (PMQ) was upwind or crosswind to the city and (b) for days when Belleville (BCC) was upwind or crosswind to the city

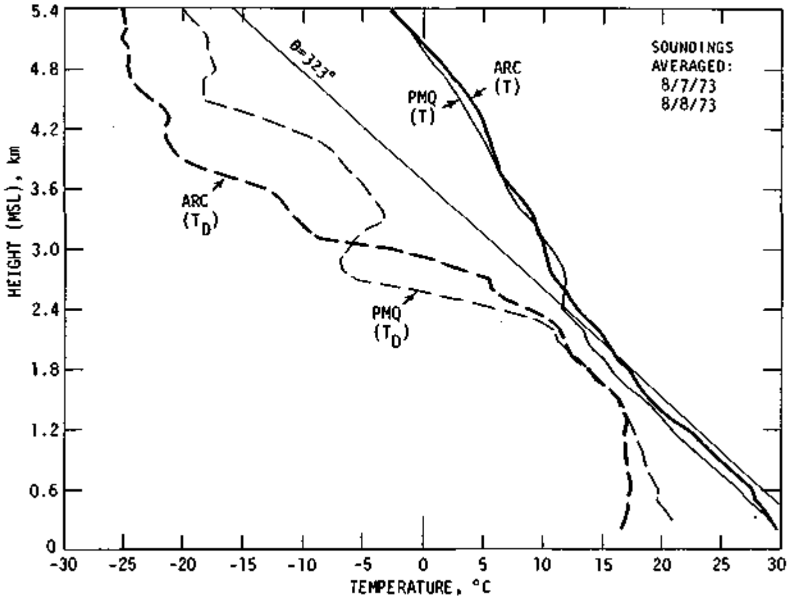


Figure J-3. Average temperature and dew point profiles at the Arch (ARC) and Fere Marquette (PMQ) for two fair days with winds from SSW to SW (PMQ unaffected by the city) of +4 or less is indicative of showers or thunderstorms. Threshold values of the LI are generally smaller than the Showalter Stability Index with large negative values usually associated with severe storms.

On 7 of the 10 cases days considered, the soundings at all three sites reached 500 mb. The mean values of the indices listed above are given in Table J-3 for each site. In general, unstable conditions were indicated for all three sites, although some of the severe storms indices were marginal. However, the average values do not indicate significantly greater or lesser instability at the urban site than at the rural location.

Table J-3. Stability Indices at 1330 CDT, Averaged for Seven Rain Days

	Stability Index (°C)				
Site	CTI	VTI	TTI	SSI	LJ
50. Belleville (Rural SE)	19.2	24.4	43.6	+1.3	-0.8
53. The Arch (Urban)	18.7	26.2	44.9	+1.5	+0.3
60. Pere Marquette (Rural, NW)	21.4	25.7	47.1	+0.2	-2.9

A comparison of the average TTI and VTI values at Belleville and the Arch when the former was unaffected by urban influences showed that the Arch averaged about 1.5°C higher on both. On the other hand, when Pere Marquette was upwind or crosswind of the Arch, its VTI averaged 0.6°C higher than that at the Arch, and its TTI averaged 3.4°C higher. In the case of the lifted index, both Pere Marquette and Belleville showed more instability than the Arch when they were in flow unaffected by the City. These results are in general agreement with the averages shown in Table J-3.

Convective Condensation Level. The height of the convective condensation level (CCL) at 1330 CDT on rain days are plotted in Fig. J-4 (see stability definitions at end of paper for computational technique). It can be seen that the CCL at the urban location was usually higher than at either of the rural locations. (The very high CCL's, 3000-5000 m, occurred on 7/27, when the rain did not start until 8 hours after the sounding time). Although the sample was small, on days when the wind in the planetary boundary layer was along the section there appears to be a tendency for the CCL to be higher downwind of the city than it was in air which has not passed over the city.

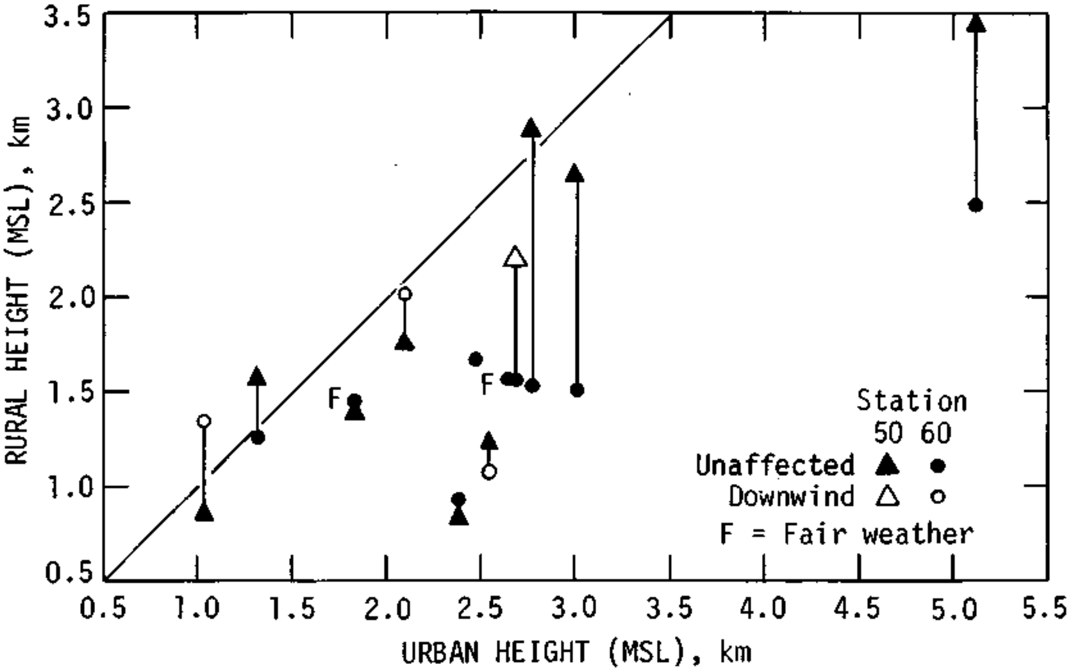


Figure *J-4. Comparison of height of the convective condensation level at the Arch and the rural stations at 1330 CDT (Symbols identify rural station and whether rural station was downwind of the city). Measurements on rain days were prior to the onset of precipitation*

The average heights and temperatures of the CCL for city locations and unaffected rural locations are given in Table J-4. Listed in the last column are the average heights for the 9 days on which data were available at all three stations. Not only were the heights of the CCL <u>greater</u>, but the temperatures and equivalent potential temperatures were significantly lower in the city than they were at unaffected rural locations. The average differences between the ARC and PMQ were considerably greater than those between ARC and BCC, and, as a corollary the CCL at BCC tended to be higher than at PMQ. Although the question of accuracy at PMQ remains, this could be due to siting. Both were basically rural sites but PMQ was completely surrounded by open country for many miles while BCC was close to the edge of a small urban area.

Table J-4. Average Heights and Temperatures of the Convective Condensation Level

	BCC Unaffected (N=8)			PMQ Unaffected (N=7)			"Complete" Data (N=9)
Site	Z (m, MSL)	T (°C)	θ_e (°A)	Z (m, MSL)	T (°C)	θ_e (°A)	Z (m, MSL)
50 BCC	1919	14.9	330.8	—	—	—	1951
53 ARC	2533	11.5	327.4	2823	9.6	324.4	2550
60 PMQ	—	—	—	1564	18.0	335.7	1523

The urban-rural differences in the CCL are in excellent agreement with observed differences in cloud base height. The BCC-ARC height difference of 600 m for the CCL is almost identical with that found by Cataneo (1973) for average cloud bases over the two locations in 1972.

The higher CCL over the city implies that the temperature in the lower 500-1000 m was higher over the city than elsewhere or that the mean moisture was lower.

<u>Lifting Condensation Level</u>. The lifting condensation level (LCL) was determined by the standard techniques (see stability definitions at end of paper), except that the temperature and humidity at the first contact on the sounding was used rather than the actual surface observations. The results were similar to those for the CCL. The LCL was significantly higher for the urban area than for the rural sites. The averages for the nine days of "complete" data were 1958 m at ARC and 1296 m and 1496 m at PMQ and BCC, respectively.

The LCL is highly dependent on surface relative humidity. Thus, the higher LCL's indicate lower surface relative humidities due to either higher temperature or lower moisture.

Mixing Height. The mixing height was computed by the method described by Wuerch (1972). The computation proved very subjective, as there were frequent shallow layers of stability. Following Wuerch's recommendation, such small layers were ignored unless a temperature line drawn to the next successive point above or below the stable layer also indicated stability. The highest value of mixing height was taken as 3000 m MSL when no lower stable layers were present.

The average heights (MSL) of the top of the mixed depth were 2223 m at ARC and 1912 and 1895 m at PMQ and BCC, respectively. However, as can be seen from Fig. J-5, the urban-rural differences are not nearly as consistent as they were for the CCL.

Low-Level Lapse Rate. The lapse rates in the lower 500 m, the lower 1000 m, and below the CCL were determined from plots of potential temperature (0) by straight line approximations between the desired level and the surface based on a downward extrapolation of the lowest segments of the radiosonde curve. This may cause some errors in the lapse rate for the first few tens of meters, particularly if superadiabatic conditions occurred close to the surface, the error in the straight line approximation to the temperature curve for the deeper layer (500 m and greater) was probably small. The average values of the lapse rates ($\Delta\theta/\Delta Z$) at the three stations are shown in Table J-5.

Table J-5. Average Value of $\Delta\theta/\Delta Z$ between the Surface and Indicated Height for the Nine Days with Complete Data (1330 CDT)

	$\Delta\theta/\Delta Z$ (°C km^{-1})		
Site	a. 500 m	b. 1000 m	c. CCL
50 BCC	0.355	.944	1.840
53 ARC	0.311	.677	2.327
60 PMQ	1.550	1.900	1.903

On the average, the urban area shows the least stability below 1 km, (in agreement with the average Vertical Totals Index in Table J-2). However, the relationship is far from consistent; in fact, the urban lapse rate was greater than the unaffected rural lapse rate as often as it was less. As is to be expected, the lowest 500 m was less stable than the lowest 1000 m, since the adiabatic lapse rate established by diurnal heating often extended only into the lowest part of the boundary layer.

The mean lapse rate to the CCL indicated the greatest stability at the urban site. This is no doubt due to the fact that the CCL was much higher

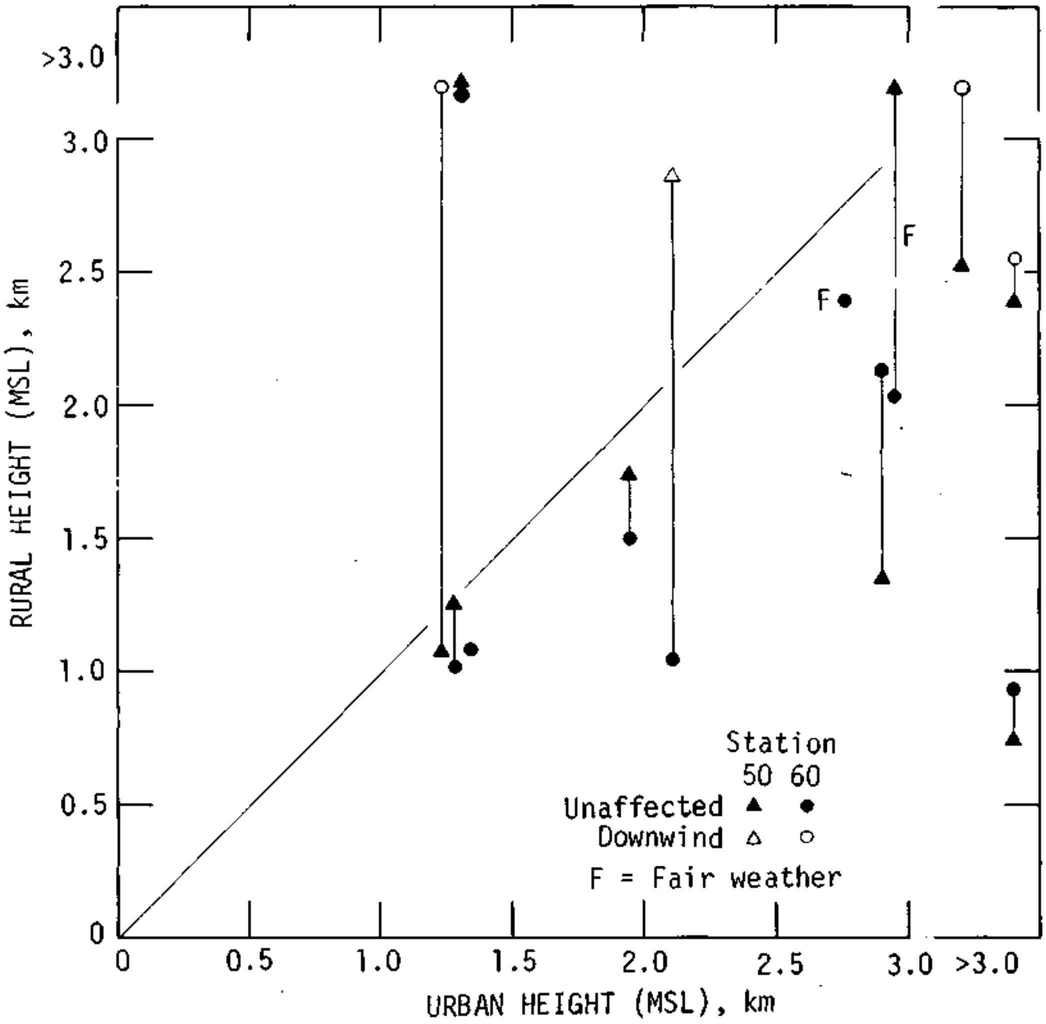


Figure J-5. Comparison of the height of the top of the mixing layer at the Arch and at the rural stations at 1330 CDT (Symbols identify rural station and whether it was downwind of the city) over the urban area, which counteracted the steep lapse rate in the lowest layers caused by diurnal heating. The increasing stability with increasing height in the lowest several kilometers is brought out very well by comparing columns a, b, and c of Table J-5. There was somewhat more uniformity in the data for the lapse rate to the CCL, with greater stability over the urban area than over rural areas on 7 of the 10 days.

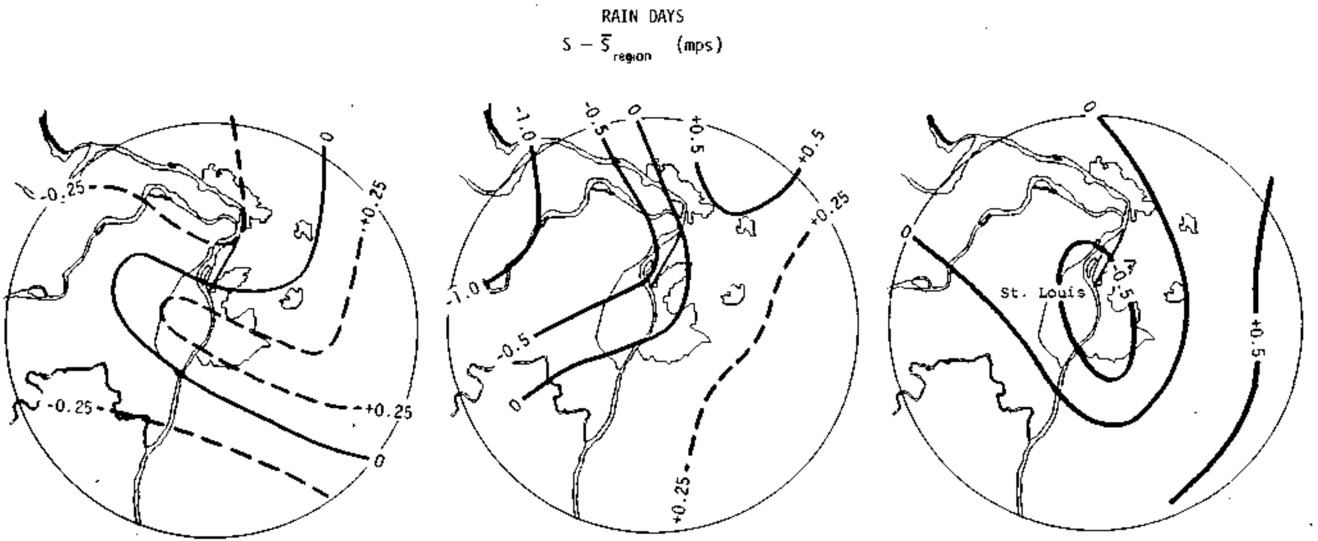
Wind Field

The wind measurements have been studied with a view toward describing the airflow and the derivative fields in the lowest two km. As in the thermodynamic study, 9 August has been omitted from the analysis because of the widespread rain in the network. In several instances the rainstorms started very shortly after the completion of the second set of pibal observations at 1330-1400 CDT. On these occasions the winds at some of the stations could have been modified by local cloud circulations. Thus, attention has been focused on the release pair (usually 1130-1200 CDT) representing conditions 1 to 3 hours prior to the onset of the rain.

The flow may be modified as air passes over a city because of a thermally-induced pressure perturbation associated with the urban heat island, change in the scale and intensity of the mechanical turbulence arising from surface roughness, and/or variations in the vertical transport of momentum associated with low-level thermal instabilities. The alterations may be manifested as changes in either speed or direction. It is this bivariate nature of the wind, coupled with changes of ambient flow, that complicate the synthesis of individual analyses into a coherent depiction of the urban influence.

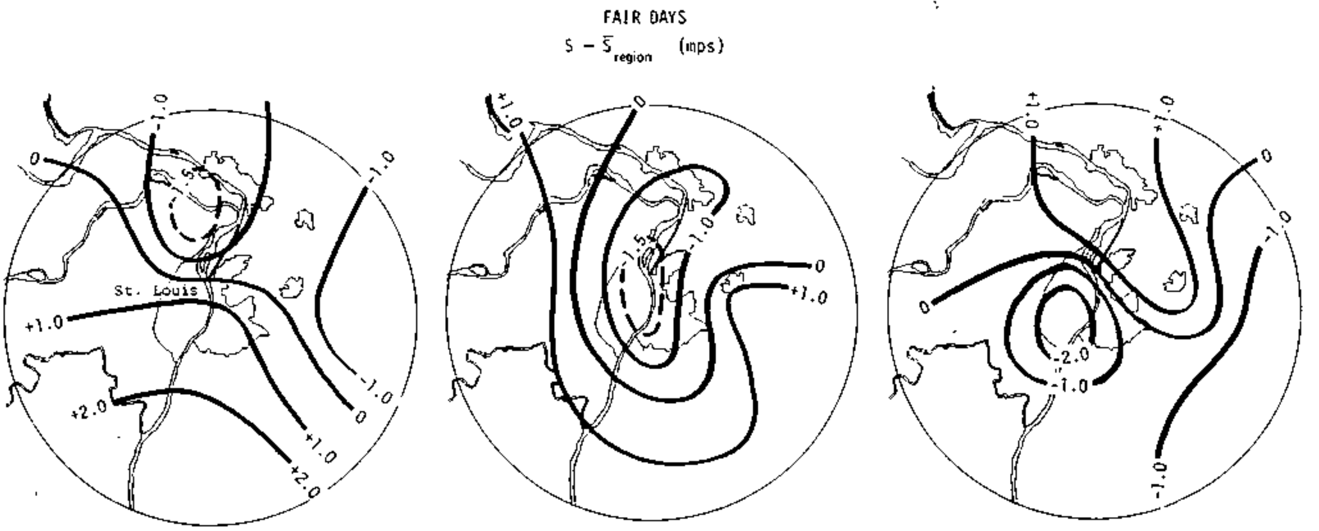
In order to minimize some of these factors, particularly those related to the ambient flow, the approach has been to composite deviation (from network mean) fields, derivative fields, and wind components along and normal to the mean flow. Due to the difficulty of determining the mean synoptic flow through the planetary boundary layer, the network (vector) average wind at each level of interest has been used as an estimate of the mean flow. Eight of the 11 rain days have been combined in the discussion below. Results for 27 July have been omitted because of the late hour of the onset of rain, and 9 August omitted because the rain was early. Analysis for 13 August was not included because gaps in data made it difficult to get a reliable estimate of the mean wind. The winds on the remaining eight rain days varied in direction from SSE to WNW. The wind fields on the two fair days are also presented. The winds were from SSE to SSW and somewhat stronger than on the rain days.

Scalar Wind Speed. It is commonly believed that the wind speed over the city should be less than elsewhere because of the greater roughness. Somewhat fragmentary evidence suggests that this is the case at the surface. In Figs. J-6 and J-7 are shown the average fields of the deviation of wind speed from network average at 500, 1000, and 1500 m MSL, for rain and non-rain days. The wind speed on the two non-rain days were about twice as strong as on the rain days,



a. 500m MSL b. 1000m MSL c. 1500m MSL

Figure J-6. Field of wind speed deviations from network mean speed, averaged from 8 rain days in 1973



a. 500m MSL b. 1000m MSL c. 1500m MSL

Figure J-7. Field of wind speed deviations from network mean speed, averaged from 2 non-rain days in 1973 averaging about 7 or 8 mps, as opposed to around 4 mps on the rain days. Nevertheless, the patterns are remarkably similar. In the lowest km, the speeds varied across the network by about 1 mps on rain days and by about 3 mps on the fair days.

At 500 m (about 300 m AGL) the greatest negative deviations (lowest wind speeds) occurred well downwind from the main metropolitan area on fair days, Fig. J-7a. On the rain days (Fig. J-6a), a band of large positive anomalies (high wind speeds), oriented roughly perpendicular to the most common wind direction, lay across the city proper. On both rain and fair days, the area of low speeds shifted upwind with height and by 1500 m MSL was centered over the main industrial region.

A separate, purely statistical study of mean deviations does not show any significant difference between rural and urban sites below 500 m AGL (about 700 m MSL). At 500 m AGL, however, the differences do become significant. In light of the obvious patterns illustrated in Figs. J-6 and J-7, the explanation appears to lie in the fact that, at the lower levels, the city affects the winds over the downwind rural areas also.

The existence of higher winds over the city at the lower levels and lower winds at the upper levels strongly suggests enhanced vertical exchange of momentum. This could be due to increase in either mechanical or thermal turbulence or both.

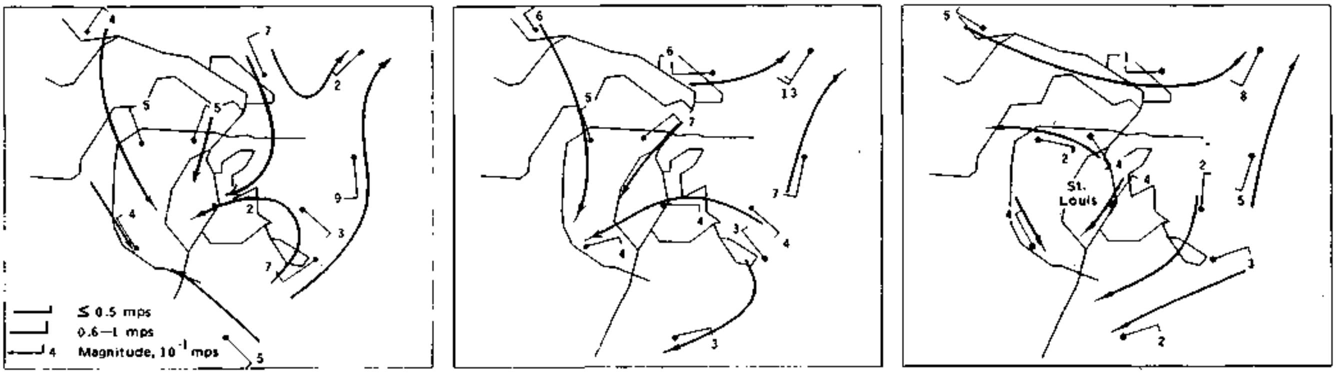
Vector Deviations. The average station vector deviations from the network vector average velocity are shown for three levels for fair and rain days in Figs. J-8 and J-9. Approximate "deviation" streamlines have been sketched. The average patterns are similar to those for the individual days - and are truly striking. Again the results for rain and non-rain days are very much alike.

A significant zone of convergence lies across the city at 500 m MSL (Figs. J-8a and J-9a). A zone of convergent flow occurred over the city at 1000 m MSL also, although the mean field appears less organized than below - particularly to the east and northeast of the city on rain days. The field is radically different at 1500 m, indicating a divergent perturbation over the city on rain days, and an anticyclonic divergent perturbation on non-rain days.

Divergence. If the flow is deformed over the city, whatever the cause and whether in direction or speed, the perturbation should be reflected in the derivative fields. Of particular interest is the horizontal divergence since enhanced divergence implies subsidence and enhanced convergence suggests a contribution toward net upward motion on the mesoscale.

The net divergences over urban and rural areas delineated by wind stations were calculated by the Bellamy method (1949). The horizontal divergence at 500, 1000, and 1500 m MSL was calculated for all possible triangular urban areas and the quadrilateral delineated by Sites 52, 53, 58, and 59, and for all possible rural triangles and quadrilaterals based on all other sites. The

DEVIATION FIELD - RAIN DAYS



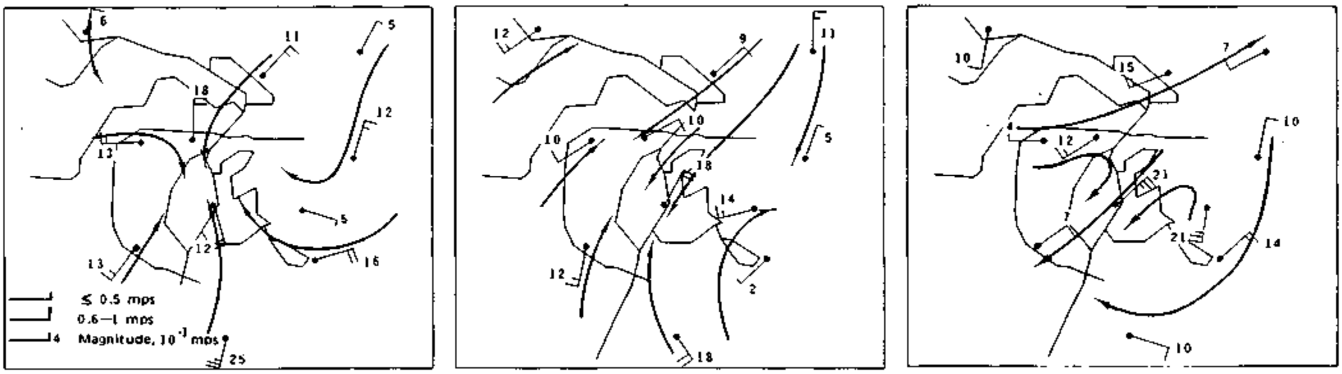
a. 500m MSL

b. 1000m MSL

c. 1500m MSL

Figure J-8. Average vector deviations from network vector mean wind for 8 rain days in 1973 (Numbers near barbs give magnitude of deviation vector in mps)

DEVIATION FIELD - FAIR DAYS



a. 500m MSL

b. 1000m MSL

c. 1500m MSL

Figure J-9. Average vector deviations from network vector mean wind for 2 non-rain days in 1973 (Numbers near given magnitude of deviation vector in mps) discussion below, however, considers only rural areas defined by the combination stations 54, 55, 56, and 57.

In Fig. J-10 the divergence calculated for the urban area is plotted against the value over a rural area of approximately equal size. All days for which adequate data are available are plotted, including the non-rain days (7 and 8 August) and 27 July, on which rain did not start until 8 or 9 hours after the observation time. Clearly, at 500 and 1000 m MSL the flow over the metropolitan area was more often convergent than divergent, whereas the reverse was true for the country area to the east. The relatively large convergences measured over the urban areas on the two non-rain days are very similar in magnitude to that observed on two similar days in 1972. Even when the flow over the rural area was convergent, the convergence over the city tended to be larger.

The magnitude of the divergences (convergences) measured at 1500 m MSL were, for the group as a whole, less than at the lower levels. Although the flow over the urban area tended toward convergence, the values were very small and approaching the limits of accuracy of the measurement. Urban-rural differences appear to be less consistent also.

The average values of the divergence for urban and rural areas are plotted in Fig. J-11 as a function of height. Only seven of the rain days are included in the averages because on 24 August, gaps in data did not permit estimation of divergence over both urban and rural areas at 1500 m MSL. Clearly during midday the flow tends to be convergent over the city in the lowest 1000-1200 m AGL in the face of generally divergent (or lesser convergent) flow over the rural sections of the region. The differences between urban and rural areas tend to vanish around 1500 m, but it is not certain that this is true above this level. Because of general cloudiness, particularly on rain days, the data tend to become fragmentary above 1500 m. As more data are processed, the analysis will be extended to the upper levels.

The reason for the higher values of convergence over the city on fair days than rain or rain days is not clear. It may be associated with the generally higher wind speeds. However, since cloud formations are not entirely restricted to the city the local cloud circulations could mask part of the urban perturbation.

The implications are fairly obvious. Convergent flow over the urban area in the lower boundary layer implies inflow from the surrounding area and ascending motion over the city, at least up to the cloud base level. This is favorable both for enhanced processing of atmospheric moisture and for increased transport of urban effluents into the clouds themselves.

Summary

The airflow over the METROMEX region is perturbed by the city on both rain and fair days. This perturbation results in a zone of convergence over the city,

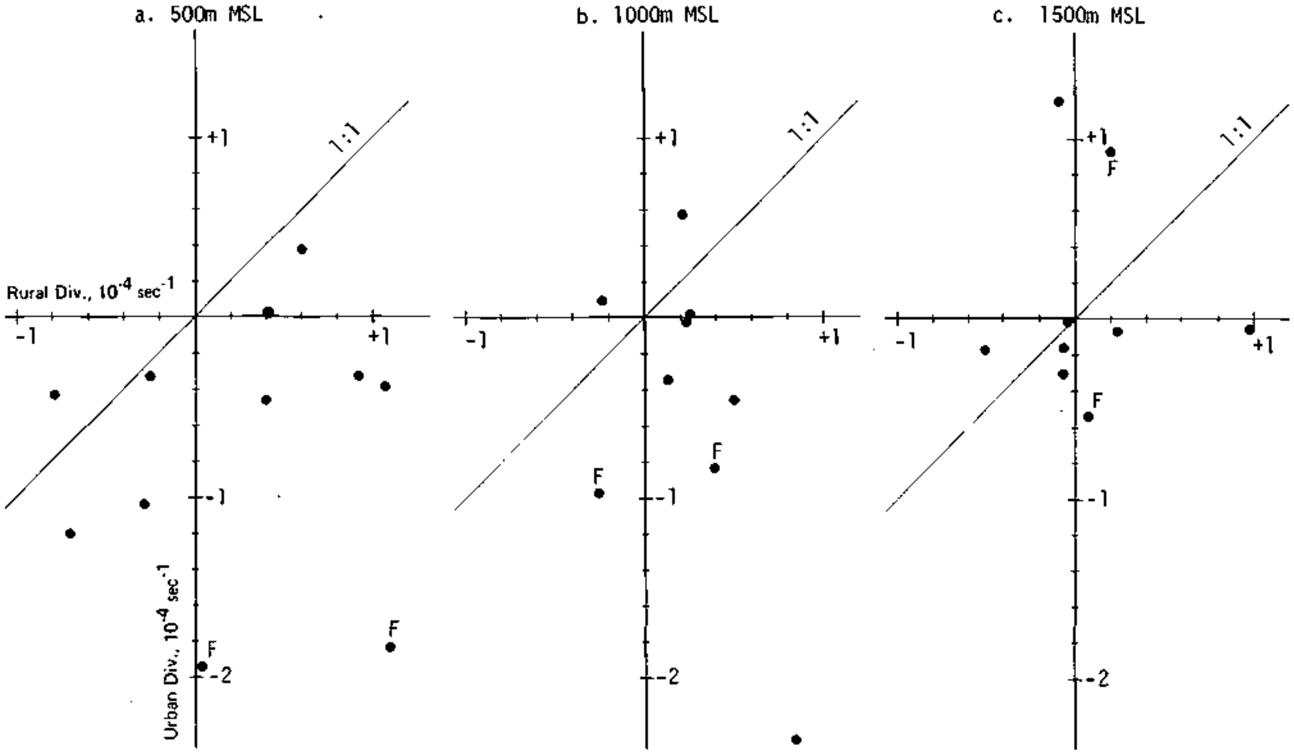


Figure J-10. Divergence (10^{-4} sec^{-1}) over the city (ordinate) vs. divergence over a rural area of comparable size (abscissa)

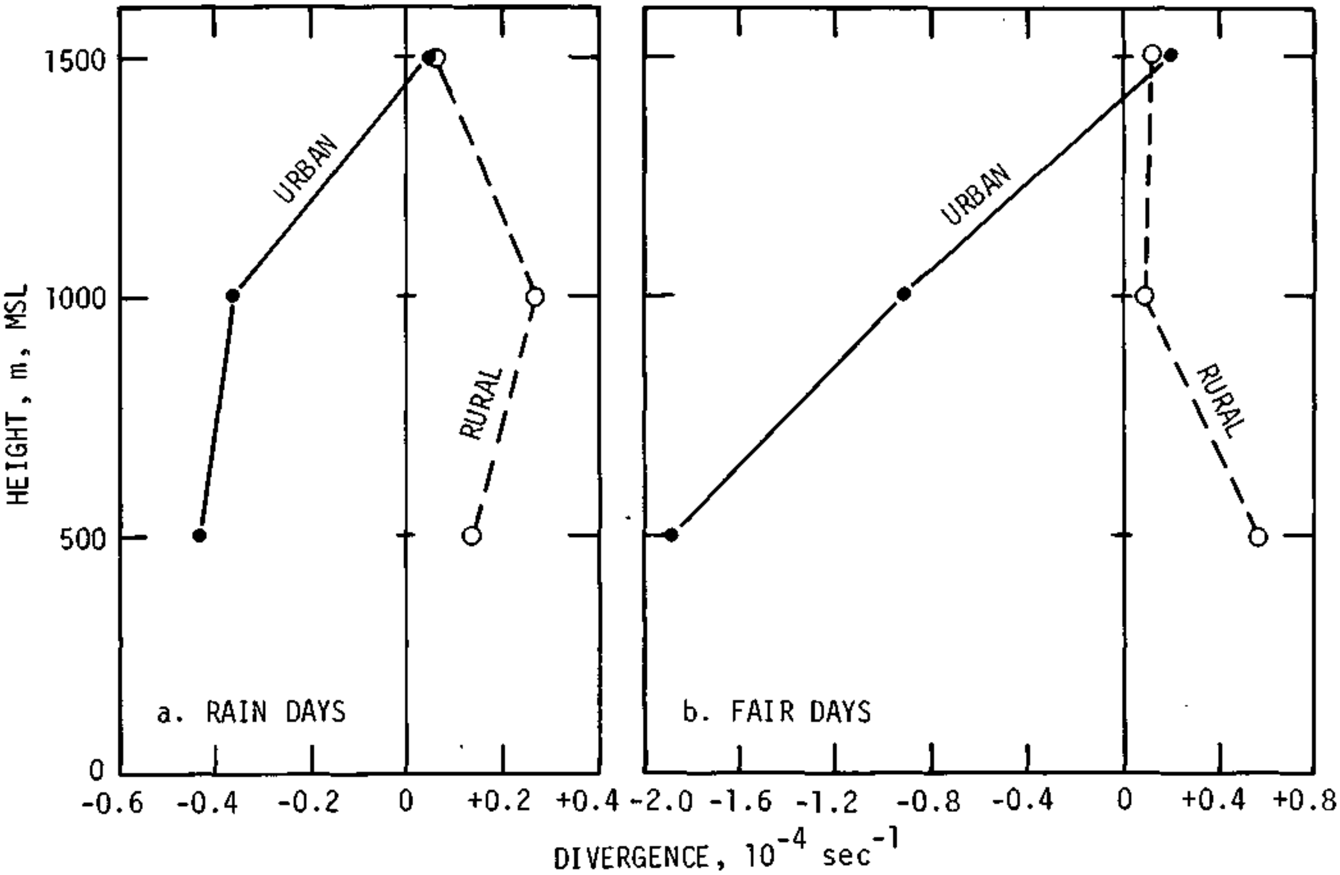


Figure J-11. Average divergences calculated over city area and country area as a function of height for 8 rain days in 19/'3 and 2 non-rain days in 1973 extending through the first km. The convergence over the city averaged about 0.4×10^{-4} sec^{-1} on rain days. This implies net upward motion through cloud base level, enhanced moisture inflow, and transport of city effluents into cloud systems.

The wind measurements also indicate significant reduction in speed downwind of the city at 500 m, and lowest average wind speeds directly above the urban area between 700 and 1200 m AGL. Enhanced vertical exchange of momentum and non-uniform flux divergence through the lowest one or two km is strongly suggested.

The various stability indices which have been developed for indicators of showers and thunderstorms were not significantly nor consistently different at the urban station than they were at the rural stations on rain days. The air tended to be a little warmer (about 1°C) and drier in the first km or two over the downtown St. Louis than over unaffected rural areas. Although on the average it was slightly less stable in the lowest 500 to 1000 m over the Arch than at the other two sites, this was not consistent from day to day.

In agreement with the higher temperatures and lower humidities, the lifting condensation level and the convective condensation level were higher over the city. The urban-rural differences in the latter agree well with differences in observed cloud base heights. The mixing depth also tended to be slightly higher over the city.

The inconclusive results from most of the thermodynamic analysis suggest that the urban-rural differences may be relatively small. If so, they could be masked by the processes involved in convective shower development. These data are being used in several exhaustive case studies of specific rain situations. These individual studies may yield a more consistent picture of the effect the city has on the thermodynamic structure.

Definition of Thermodynamic of Indices

CTI: The 500-mb temperature subtracted from the 850-mb dew point (Miller, 1967).

VTI: The 500-mb temperature subtracted from the 850-mb temperature (Miller, 1967).

TTI: The sum of the CTI and VTI (Miller, 1967).

SSI: The temperature at the intersection of the saturation adiabat through the 850-mb lifting condensation level and the 500-mb level subtracted from the 500-mb temperature (Showalter, 1953).

LI: The temperature at the intersection of the saturation adiabat through the lifting condensation level for the mixed lowest 3000-foot layer and the 500-mb level subtracted from the 500-mb temperature (Winston, 1956).

CCL: The intersection of the temperature profile with the saturation mixing ratio line corresponding to the average mixing ratio in the lowest 50-mb (approximately 1500 ft.), (Huschke, 1959).

LCL: The intersection of the dry adiabat through the parcel's original pressure and temperature with the saturation mixing ratio line having the same value of the mixing ratio as the parcel (Huschke, 1959).

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K. METROMEX CLOUD CAMERA STUDIES FOR 1971-1973

Paul T. Schickedanz

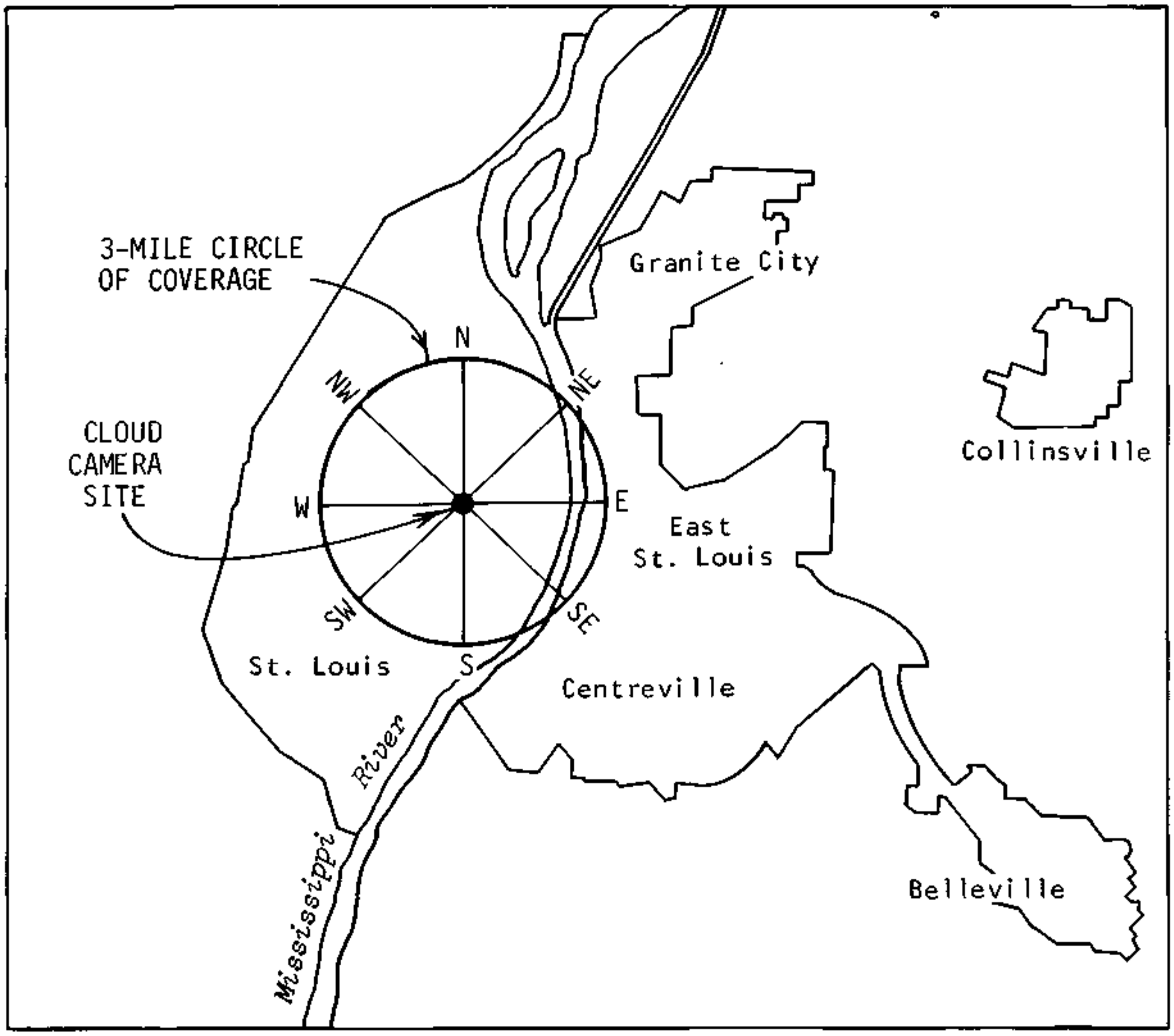
Introduction

During 1971-1973 an all sky camera was installed and operated for the purpose of visually recording clouds in the vicinity of the 3-mile circle shown on Fig. K-l. The film data were used to determine preferred areas of cloud initiation in the central city region. The camera system consisted of a reflecting dome of approximately 7-inch diameter, a 16-mm camera mounted approximately 21 inches above the dome surface, and a clock to record the time of observation. Data were collected for most days during August 1971, June-August 1972, and June-August 1973. However, not all of these data were useable because of clock stoppage, poor quality of film, over-exposure, inadequate focusing of camera, and deterioration of the paint on the reflecting globe. Thus, only part of the data could be analyzed for cloud initiation studies. These problems in the data collection system reduced the data sample to seven cloudy periods in 1971, 37 in 1972, and 14 in 1973.

Analytical Procedures

For each cloudy period, the distance and direction of the first 5 and first 10 clouds to initiate were determined. The determination was made by projecting the film data on a wall screen and then overlaying the screen with a circle of 3-mile radius. The distance was determined by using the assumptions that the lens-mirror system was azimuthally equidistant (Holle and MacKay, 1972) and that cloud base was at 4,000 ft. The azimuthally equidistant assumption means that the relation is linear between zenith angle and distance of the image point from the picture center. The location and direction data were then partitioned into clouds — 3 miles and those > 3 miles from the camera center. The resolution of the lens-mirror system when 16-mm film is employed make it extremely difficult to obtain quantitative distances beyond three miles. The data were also partitioned into eight sectors of the circle corresponding to 337.5-22.5 degrees (N), 22.5-67.5 degrees (NE), 67.5-112.5 degrees (E), etc. Results are summarized in Table K-l.

For the overall period, the greatest percentage of cloud initiations was N of the site (20%), while the second greatest percentage was W of the site (18%). During 1971 and 1973 the greatest percentage of cloud initiations was N of the site, but during 1972 the maximum was located W of the site. Percent frequencies according to direction and for distances — 3 miles were also computed for the first 10 clouds to initiate. For the overall period, the greatest frequency of cloud initiation was again N of the site (19%) and the second greatest frequency occurred to the W of the site (17%).



Figuve K-1. Location of the cloud camera and 3-miZe circle of coverage

Table K-1. Percent Frequency of the First Five Clouds to Initiate ≤ 3 Miles of the Camera Site According to Direction

	Percent Frequency to Initiate in Given Direction								Sample
		N	NE	E	SE	S	SW	NW	Size
1971	27	17	10	0	13	3	20	10	30
1972	17	13	6	6	12	12	21	13	144
1973	23	13	11	16	7	7	11	12	56
1971-73	20	13	8	8	11	10	18	12	230

The first 5 clouds and the first 10 clouds to initiate according to direction, but irrespective of distance, was determined and the percent frequency of cloud initiations is list in Table K-2.

Table K-2. Percent Frequency of the First Five Clouds and the First Ten Clouds to Initiate at all Distances According to Direction (1971-1973)

	Percent Frequency to Initiate in Given Direction								Sample
	N	NE	E	SE	S	SW	W	NW	Size
First 5 Clouds	20	13	8	8	11	9	19	12	255
First 10 Clouds	19	12	7	8	13	9	18	14	468

Thus, regardless of whether the stratification of cloud initiation is based on the first 5 clouds, first 10 clouds, or according to distance, the most frequent initiation of clouds occur to the W and N of the camera site. Since clouds move most frequently with a W-E component, the high frequency of cell initiations to the W as opposed to the E may partially be influenced by clouds moving into the camera's field of view and producing "apparent" initiations. However, there is no reason for the high frequency of cell initiations to occur to the N as opposed to the S.

Conclusions

The initiation frequencies of first clouds during a cloudy period is greatest to the N and to the W of the camera site. The high frequency to the W may be biased by clouds moving into the camera's field of view and producing "apparent" initiations. However, there is no known reason for the high frequency to the N to be biased. This area of high frequency of cloud initiations is approximately five miles WSW of a known raincell initiation area at Granite City (see Section D). It is quite possible that the above cloud-raincell initiation region is coupled.

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L. HYDROMETEOROLOGICAL ANALYSES OF METROMEX RAINCELL DATA*

Floyd A. Huff

Introduction

As part of the METROMEX research, analyses are being made of potential urban effects upon heavy rainfall events. If urban areas intensify or moderate naturally occurring heavy rainstorms, the frequency and magnitude of flood-producing storms within and downwind of these areas will differ from those experienced in rural areas. This would affect the design requirements for urban, and, possibly, suburban sewer systems, the potential urban effect on heavy rainfall distribution has become increasingly important with the present emphasis on improved sewer system design and engineering. There is increasing nationwide concern with sewer surcharging and such allied problems as basement inundations from storm water, particularly in view of current federal and state environmental regulations. As a result, information on rainfall frequencies expected to occur several times per season, on the average, has become of much greater importance to the hydrologist. The METROMEX Network is the largest urban network in existence, and, therefore, provides an excellent opportunity to improve our knowledge of the urban effect upon all types of precipitation.

The material presented here is not intended to reflect long-term relations, since the 2-summer sample (1971-1972) is not adequate for this purpose. However, with 225 gages distributed over a 2100-mi^2 area, a relatively large sample of 1475 raincells was collected. By investigating the properties of the more intense cells among this 1475-cell sample, much can be learned about the general characteristics of these small-scale events and their importance in urban hydrology, especially those rainfall properties applicable to the various problems of urban sewer design and engineering. Network raincell data collected over several years, such as is being done in the St. Louis project, can be particularly useful in defining short-period rain rates expected to occur several times per year or season. For example, the 2-year METROMEX sample was of considerable help to the author in a recent study performed for the Illinois Environmental Protection Agency who needed information on the frequency of seasonal precipitation amounts expected to occur one to five times per season for time intervals of 5 to 60 minutes.

In the following text, the properties of intense raincells, as reflected in the 1971-1972 data, will be summarized and urban influences discussed. Raincells, which are determined from 5-minute rainfall amounts at the 225 raingages, are the basic storm unit from which heavy, short-duration rates

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* Condensed version of paper presented at the National Symposium on Urban Runoff, University of Kentucky, July 28-31, 1974, and published in the Symposium Proceedings.

develop in thunderstorm-dominated climates, such as the Midwest. Also, the characteristics of maximum 5-minute rain rates occurring with raincells will be described, and possible urban effects on their properties discussed. The definition of a raincell is the same as that used by Schickedanz in an earlier section of this report, and described in detail in an earlier paper (Schickedanz, 1972).

Raincell Properties

From the sample of 1475 raincells, the 100 cells having the heaviest mean rainfall were selected for detailed analyses. In evaluating the general characteristics of intense raincells, numerous definitive parameters were determined. These included the mean rainfall, maximum and minimum point rainfall, area encompassed, duration, rainfall volume, movement, path length, rainfall gradient, maximum 5-minute average rainfall within the cell's lifetime, maximum area encompassed in any 5-minute period, and maximum rainfall volume produced in any 5-minute period. The time of initiation of each cell was determined to ascertain whether preferential periods of occurrence prevailed. The synoptic storm type associated with each cell was also recorded to determine if the intense cells were biased toward development in particular types of weather conditions.

A number of the above statistical parameters have been summarized in Table L-1. In this table, medians are shown for the raincells grouped into classes of 10, starting with those having the heaviest cell mean rainfall. The means for the sample of 100 cells are shown at the bottom of the table. Table L-l shows the cell means decreasing from a 0.78-inch median for the heaviest 10 raincells to 0.32 inch for the lightest 10. Overall, records show that the heaviest raincell mean was 0.89 inch and the lowest was 0.30 inch.

Except for maximum point rainfall, no very distinct trends are indicated with decreasing rainfall intensity among the other parameters; that is, there is no strong relationship between cell mean rainfall and area, duration, volume, and the other parameters which help define the cell characteristics. However, there are some weak trends indicated; for example, cell duration tends to shorten with decreasing mean rainfall. Another such trend is evident also in the point rainfall gradient and the area-depth slope. The area-depth slope is taken from the area-depth curve traditionally employed in hydrologic analyses of rainfall data to obtain a mathematical expression of the rainfall distribution. This curve relates area to mean rainfall, maximum point rainfall is the y-intercept, and basin mean rainfall is the end-point of the curve (Huff and Stout, 1952).

The relative high values of raincell area, duration, volume, and path lengths in ranks 11-20 of Table L-l are of interest. Analyses shows that several of the cells with very intense rainfall in ranks 1-10 were of small areal size and duration. Actually, the larger storms with relatively high means and areal sizes were in the second rank group. These larger cells tend to last longer, and, consequently, to travel farther and produce a greater total rainfall yield (rainfall volume). Thus, in this 100-cell sample, it appears that those of greatest hydrologic consequence were not necessarily cells producing the highest means. The 100-sample means at the bottom of Table L-1 provide an indication of the typical heavy raincell properties. These cells (based on the 2-season operation) had a mean rainfall of approximately 0.5 inch. On the average, they encompassed about 50 mi^2, lasted about 45 minutes, traversed 5 miles, and yielded approximately 1200-1300 acre feet of rainwater. A typical rainfall gradient would be 0.2 in/mi.

Table L-l. Raincell Median Properties in 100 Cells Having Heaviest Mean Rainfall in 1971-1972 Summers

Cell Ranks	Ave. Cell Rain (in.)	Cell Area (mi^2)	Cell Dur. (min.)	Cell Volume (acre/feet)	Path Length (mi)	Max. Point Rain (in.)	Point Rainfall Gradient (in./mi)	Area-Depth Slope (in./mi^2)
1- 10	0.78	24	50	944	4	1.32	0.34	0.061
11- 20	0.59	70	48	1765	10	1.03	0.20	0.055
21- 30	0.51	28	30	764	4	0.81	0.22	0.053
31- 40	0.47	37	47	950	6	0.71	0.19	0.036
41- 50	0.44	28	43	648	4	0.63	0.19	0.032
51- 60	0.42	42	43	831	5	0.75	0.17	0.044
61- 70	0.38	28	30	560	5	0.71	0.15	0.029
71- 80	0.35	28	32	545	4	0.43	0.11	0.016
81- 90	0.33	56	35	1005	5	0.59	0.12	0.033
91-100	0.32	37	25	621	3	0.57	0.18	0.046
100-Sample Means	0.48	52	45	1271	5	0.79	0.21	0.052

The movement of intense raincells is an important factor that has application in determining the properties of urban runoff. Analyses showed that the heavy cells moved most frequently from 250° to 290°, that is, from WSW through W to WNW. This range included 32% of the cells. Treated on a quadrant basis, the SW quadrant was most favored with 33% of the cases, followed closely by the NW quadrant with 32%. Approximately 19% of the cells were found to remain quasi-stationary after development. Cells moved least often from the SE quadrant which included only 6% of the cases.

Analyses of the time distribution showed that the intense cells develop most frequently from 1600-1800 CDT. During this period, 33% of the cells were initiated, and 65% developed in the 1200-1800 period.

Analyses of the synoptic weather types associated with the 100 raincells showed that 50% occurred with organized squall lines or squall zones , and cold fronts accounted for 35% of the cases. The isolated air mass storm was found to be associated with only 11% of the heavy raincells. Thus, the 2-season analyses indicate that the intense cells, which are primarily responsible for the heavy, short-duration rates in the Midwest, are most likely to move from the WSW to WNW, to occur in late afternoon, and to be associated with organized weather systems (squall lines or zones and cold fronts).

It is interesting to compare the water yield from these 100 raincells with that from all 1475 cells analyzed from the 1971-1972 operations. Calculations indicate that the 100 heavy cells contributed approximately 49% of the water yield on the network from the 1475 raincells. The weight which these cells exert in determining the magnitude of any urban effect is obvious from the above calculations. Huff and Changnon (1972) have indicated from long-term climatic studies that the urban effect (when present) appears to result primarily from intensification of naturally occurring rainstorms of moderate to heavy intensity. The above raincell yield properties support the earlier finding achieved with much coarser data samples.

The method by which the urban environment can strongly affect the development and/or intensification of rainstorms is illustrated by reference to the storm of 10 August 1972. The total rainfall pattern for this storm is illustrated in Fig. L-1. The major storm center was located 5-10 miles east of the urban area of St. Louis where amounts exceeded 2.5 inches. This urban-related storm occurred in the late afternoon and early evening (1615-1930 CDT), and 2-hour amounts recorded at the storm center occur at a given point in this region on the average of only once in 10 years (Huff and Neill, 1959). The storm developed from a parent raincell with previous urban exposure near the southern edge of Collinsville (Fig. L-1). This cell developed a mesoscale circulation, remained quasi-stationary for over two hours, and maintained itself by ingesting 11 separate raincells. Radar observations showed that most of these cells developed over the urban area, moved downwind, and merged with the parent system. The parent cell from which the storm evolved is shown in Fig. L-2, and Fig. L-3 illustrates the cellular structure of the storm during the period of maximum rainfall intensity.

Comparison Between Urban-Effect and No-Effect Raincells

Additional information on the urban effect was obtained through comparative analysis of those raincells which were exposed to urban effects with those that were not. A cell was considered to be potentially urban-effected if it developed over or passed through either of the two major urban-industrial areas of St. Louis and Alton-Wood River (see locations in Fig. L-l). The no-effect or control cells had no exposure to the urban areas or to either of two potential topographic influences. These included cells developing over the Ozark Hills, a few miles SW of St. Louis, or in the bottomlands of the Missouri River NW of St. Louis and west of Alton-Wood River (Fig. L-l). The bottomlands are a heat-moisture source conducive to convective cloud developments, and the hills accelerate both the development and intensification of storm clouds.

11 AUGUST 1972 TOTAL RAIN

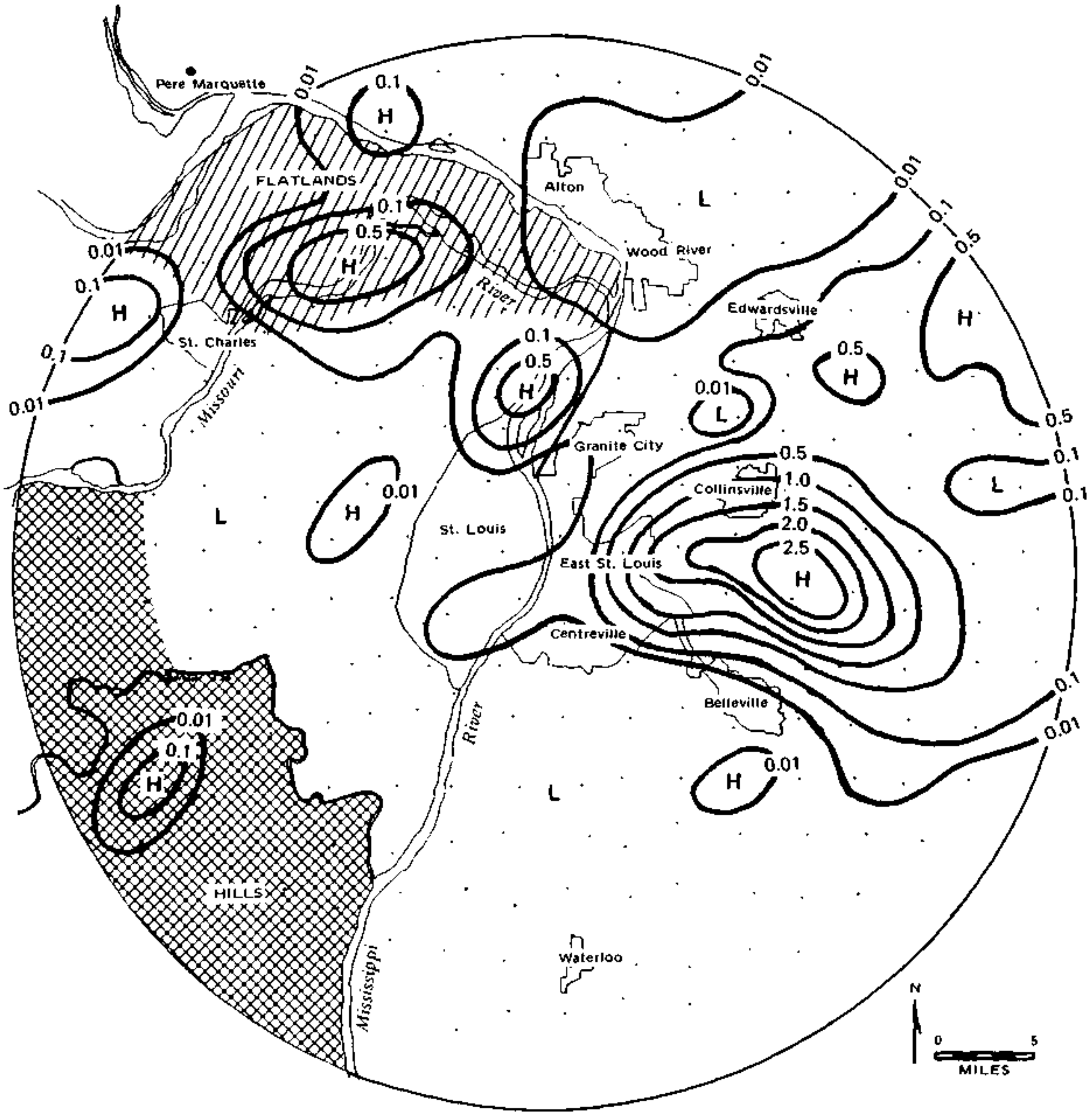

Figure L-1. Total rainfall (inches) in storm of 11 August 1972

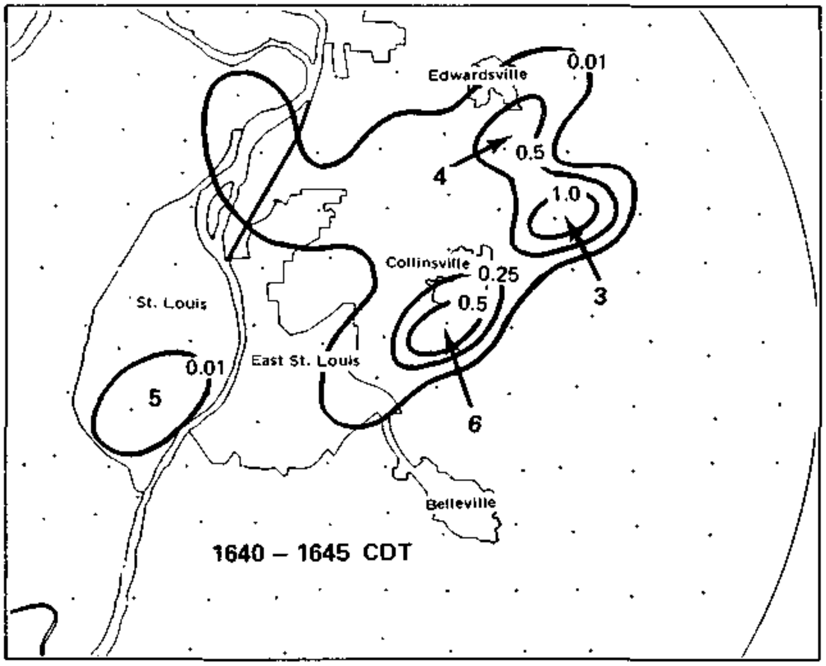

Figure L-2. Raincell structure during formation of parent cell on 11 August 1972

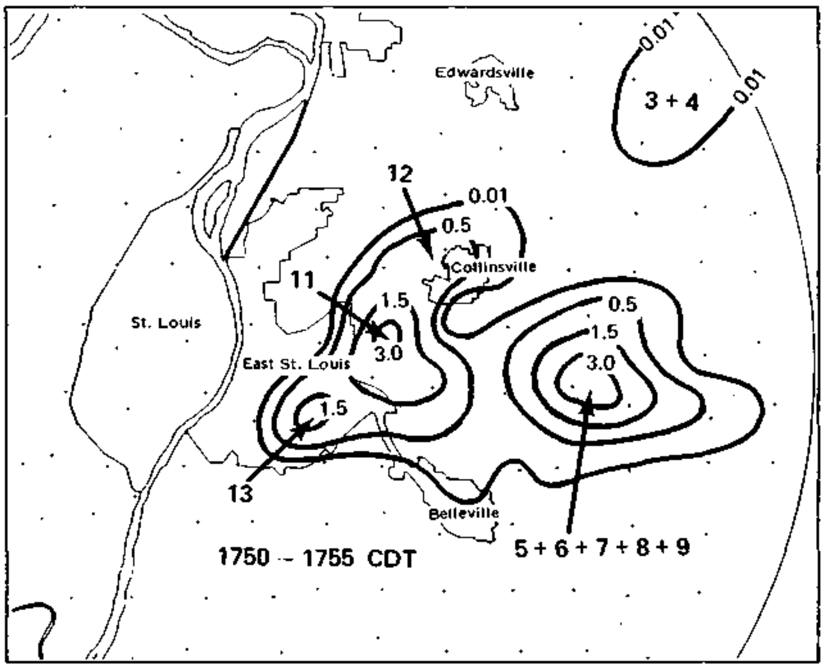

Figure L-3. Raincell structure during period of maximum rainfall intensity on 11 August 1972

The sample of 100 raincells contained 31 cells exposed to the St. Louis urban area, 11 potentially affected by Alton-Wood River, and 44 control cells. The other 14 cells had hill or bottomlands histories or a combination of hill-urban or bottomlands-urban. Because of sample sizes, the urban cells for St. Louis and Alton-Wood River were combined to provide a 42-cell sample for comparison with the nearly eqyall 44-cell control sample. If the urban environment substantially increases the rainfall in relatively intense raincells, it would be expected to be reflected in the rainfall yield from the two sets of cells. Results showed the median volume of the combined urban cells to be 1120 acre feet compared with 710 acre feet for the control cells. This represents a median water yield increase of 58% in the urban-exposed cells, and is considered strong evidence that the urban environment is substantially modifying the rainfall from raincells having moderate to heavy intensity resulting from natural atmospheric processes.

Medians have been used instead of means in the comparisons of effect and no-effect cells because of the extreme skewness of the rain volume distributions. The medians provide a conservative estimate of the apparent urban effect during the 1971-1972 period, since use of the means indicated even greater urban-effect increases than those obtained with the medians. Comparison of percentage frequency distribution curves constructed for the raincell volumes from the urban-effect and the no-effect raincells showed greater percentage and absolute magnitude differences with increasing cell rainfall volume. This is illustrated in Table L-2 in which the ratio of the urban-effect to the no-effect volume and actual volume differences have been tabulated for selected intervals along the frequency curve. Thus, the highest 30% of the rainfall volumes in the urban raincells were 88% or more (ratio of 1.88) greater than those in the no-effect cells, and this corresponds to a curve difference of 930 acre feet. This table provides further evidence of the increasing urban effect with increasing raincell yield from natural causes.

Table L-2. Comparison of all Urban-Effect and No-Effect Percentage Frequency Curves Derived from 1971-1972 Raincell Volumes in 100 Heaviest Cells

Cumulative Percent of Raincells	Difference, Effect-No-Effect Equalled or Exceeded (acre feet)	Ratio Effect/No-Effect
5	3730	2.30
10	2200	1.98
20	1350	1.93
30	930	1.88
40	620	1.73
50	410	1.58
60	270	1.45
70	145	1.30
80	50	1.12
90	-20	0.94
95	-40	0.82

The importance of determining the urban effect on existing raincells of moderate or greater intensity is further indicated by other analyses. Thus, the total volume of rainfall from the 31 heavy cells considered to be urban-effected by St. Louis was 49% of the total volume produced by 328 such cells in the 1971-1972 sample of 1475 cells. Similarly, the 11 Alton-Wood River cells among the 100 heavy raincells accounted for 82% of the total rain volume from the 70 cells classified in this category during the 2-summer period. The foregoing raincell analyses raises a serious question as to the reliability of existing rainfall frequency relations upon which urban and suburban sewer design is based. Our urban studies completed to date suggest a -possible need to re-evaluate these frequency relations in major urban areas to prevent under-design of future systems and additions to existing systems.

5-Minute Rainfall Rates

The statistics derived for total cell rainfall were supplemented by computations of the properties of maximum 5-minute rainfall periods' occurring during the life of each cell. For the 100 heavy raincells, the maximum 5-minute mean rainfall within the cell was found to range from 0.68 to 0.06 inch with a mean of 0.27 inch. The maximum corresponds to an average rate of 8.16 in/hr and the mean to a rate of 3.24 in/hr. - Over 50% of the cells had 5-minute rates exceeding 3 in/hr.

The area encompassed by these maximum 5-minute rainfalls ranged from 84 to 9 mi^2 with a median of 25 mi^2. The water yield, as measured by the 5-minute maximum rainfall volume, ranged from 2394 to 48 acre feet among the 100 cells. A comparison of the maximum 5-minute rainfall volumes in the St. Louis urban-effect raincells and the no-effect raincells indicated an urban median of 299 acre feet compared with a no-effect median of 248 acre feet. This represents a 21% greater water yield from the urban-effect storms, and provides evidence that the maximum 5-minute rates are also influenced by the urban environment.

Summary and Conclusions

The METROMEX rainfall data are providing data and information which should be of considerable use to the urban hydrologist. This section of the interim report has been concerned with a preliminary hydrometeorological study performed on data collected in the 1971-1972 period. In this study, raincell data derived from 5-minute rain amounts have been used to investigate some of the urban hydrologic aspects. A comparison was made of raincells exposed to the urban-industrial environments of St. Louis and nearby Alton-Wood River (effect cells) with those which did not develop or pass across the potential urban-effect region (no-effect cells). This analysis indicated a substantially greater water yield (rainfall volume) from the potentially urban-effected cells. Only the 100 cells with heaviest mean rainfall were used in this study to restrict comparisons to rain intensities and cell outputs that would have implications in sewer design in urban and suburban areas affected by inadvertent weather modification.

A comparison of 44 no-effect with 42 urban-effect cells with relatively-heavy water yields showed a median output of 1120 acre feet from the effect cells compared with 710 acre feet from the no-effect cells. Frequency curves constructed for the 2-summer period showed that the differential output increased both in actual magnitude and in percentage as the volume of the comparative cells increases; that is, the urban effect appears to increase in moderate to heavy rainfalls produced by natural atmospheric processes. Furthermore, comparison of the total output from the 100 heaviest cells with the rain yield from all 1475 cells analyzed for 1971-1972 showed that a highly disproportionate amount of both the natural and potentially urban-augmented rainfall was associated with the 100 heaviest cells. Thus, the 31 heavy cells exposed to St. Louis urban effect accounted for 49% of the total rainfall from the 328 cells of this type in the 2-summer period; 82% of the Alton-Wood River cell rainfall came from 11 heavy cells among a total of 70 cells; and 40% of the control cell rainfall was associated with 9% of their total number which fell into the 100-cell sample of heavy cells.

A major hydrologic implication from the studies to date is that rainfall rate frequency distributions may vary significantly between the urban, suburban, and rural areas in large urban-industrial regions. If further studies verify this distribution, it may be necessary to re-evaluate sewer design storm parameters to prevent underestimate of runoff relations in and downwind of these urban areas. More firm conclusions of the hydrologic aspects will be possible when the 5-year project is completed in 1975.

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M. EFFECT OF PRECIPITATION SCAVENGING OF AIRBORNE AND SURFACE POLLUTANTS ON SURFACE AND GROUND WATER QUALITY IN URBAN AREAS

Floyd A. Huff

Introduction

In conjunction with the METROMEX Project, a 2-year study has been undertaken to investigate the effects of increasing concentrations of urban pollutants and urban modification of regional precipitation on the water quality of surface water supplies and shallow groundwater aquifers. The study is being carried out in the East St. Louis area where both scientific effectiveness and economical operation of such a project can be optimized in conjunction with the extensive data collection and analyses projects of METROMEX. This area offers an excellent opportunity to evaluate urban-related effects on: 1) shallow aquifers which are subject to relatively rapid recharge from rainfall, and which are the primary source of water supply in the second largest industrial area in Illinois (East St. Louis region), and 2) the pollution of streamwaters, and, therefore, surface water supplies, resulting from washout of atmospheric pollutants and overland flushing of ground-based pollutants from storm runoff. This research is being supported by NSF Grant GK-38329 to R. J. Schicht,hydrologist, and F. A. Huff, Senior Meteorologist, on the Water Survey staff. This grant permits an expansion of the preliminary study described by Huff (1973).

Description of Groundwater Study

The East St. Louis area, known locally as the "American Bottoms", is in southwestern Illinois and includes an area of about 175 mi^2. It is approximately 30 mi long and 11 mi wide at the widest point, and lies completely within the METROMEX network area. The East St. Louis area has been one of the most favorable groundwater areas in Illinois. It is underlain at depths of 170 feet or less by sand and gravel aquifers that have been prolific sources of water for more than 50 years. The available groundwater resources have promoted industrial expansion of the area and also facilitated urban growth. Recharge to the aquifer is primarily from precipitation, induced infiltration of Mississippi river water, and subsurface flow of water from the bedrock bluffs that border the area. Schicht (1965) estimated that recharge from precipitation averages about 7.8 inches per year.

The groundwater quality network consists of six wells from which water samples are collected weekly for analysis of trace metals, chlorides, nitrates, sulfates, and total dissolved minerals. The wells are located away from the effects of recharge from induced infiltration from the Mississippi River and away from the effects of recharge from subsurface flow from the bedrock bluffs bordering the area. Three wells are large-capacity wells and three are small-diameter wells penetrating only the top of the water table. These wells are useful in studying infiltration from individual storms on groundwater quality.

During 2-week periods in June and September, a large number of water samples are collected from 50-75 wells for analysis. Groundwater levels normally recede during this period, indicating little recharge from rainfall. At the same time, groundwater levels are measured in approximately 200 wells to obtain data for preparing piezometric surfaces and water-level change maps.

The effects of the rainfall contribution to the groundwater reservoir and any change in groundwater quality are being studied through use of rainwater quality data collected on METROMEX. A groundwater quality map is one of the end-products of this study; this map will be very useful for future detection of any long-term changes in groundwater quality in the region.

Description of Surface Water Study

This research activity provides an excellent opportunity to accumulate information and knwoledge on the pollution of streamwaters, and, therefore, surface water supplies, resulting from washout of atmospheric pollutants and overland flushing of ground-based pollutants from storm runoff. Fortunately, for the purpose of such a study, two small basins, Canteen Creek (22 mi^2) and Indian Creek (37 mi^2) lie within the METROMEX Network (Fig. M-1). Both are in "downwind" areas subject to urban effects, and are located near the area of maximum rainfall on the METROMEX Network in the 1971-1973 period. Efforts are being made to separate streamwater pollution into three categories which include precipitation washout, atmospheric dry deposition carried to the stream by surface runoff, and all other surface pollutants combined and flushed into the stream by runoff.

In the surface water study, weekly streamwater samples are taken in the period from September through May, preceding the summer METROMEX operations to obtain a measure of the background pollution level. During the summer, both weekly and sequential storm samples of streamwater are made. Sequential samples are taken at 30-minute to 1-hour intervals on selected storm days. These include days with rainfall of varying intensity, duration, and volume. These samples provide knowledge on the time distribution characteristics of streamwater pollution resulting from atmospheric and surface pollution sources. Chemical analyses are made for the same constituents used in the groundwater studies.

The time distribution of streamwater pollution is being related to meteorological conditions. This should yield useful information on the pollution potential under different types of synoptic weather conditions and with various precipitation types, rainfall intensity, and storm duration. Similar relations between groundwater pollution and meteorological conditions will be investigated.

The results of this study is expected to provide knowledge on the time lag and time distribution characteristics of atmospheric pollutants entering surface water supplies through precipitation washout in storms of various magnitude, and information on the time distribution and concentrations in streamwater of surface sources of water supply pollution under different storm

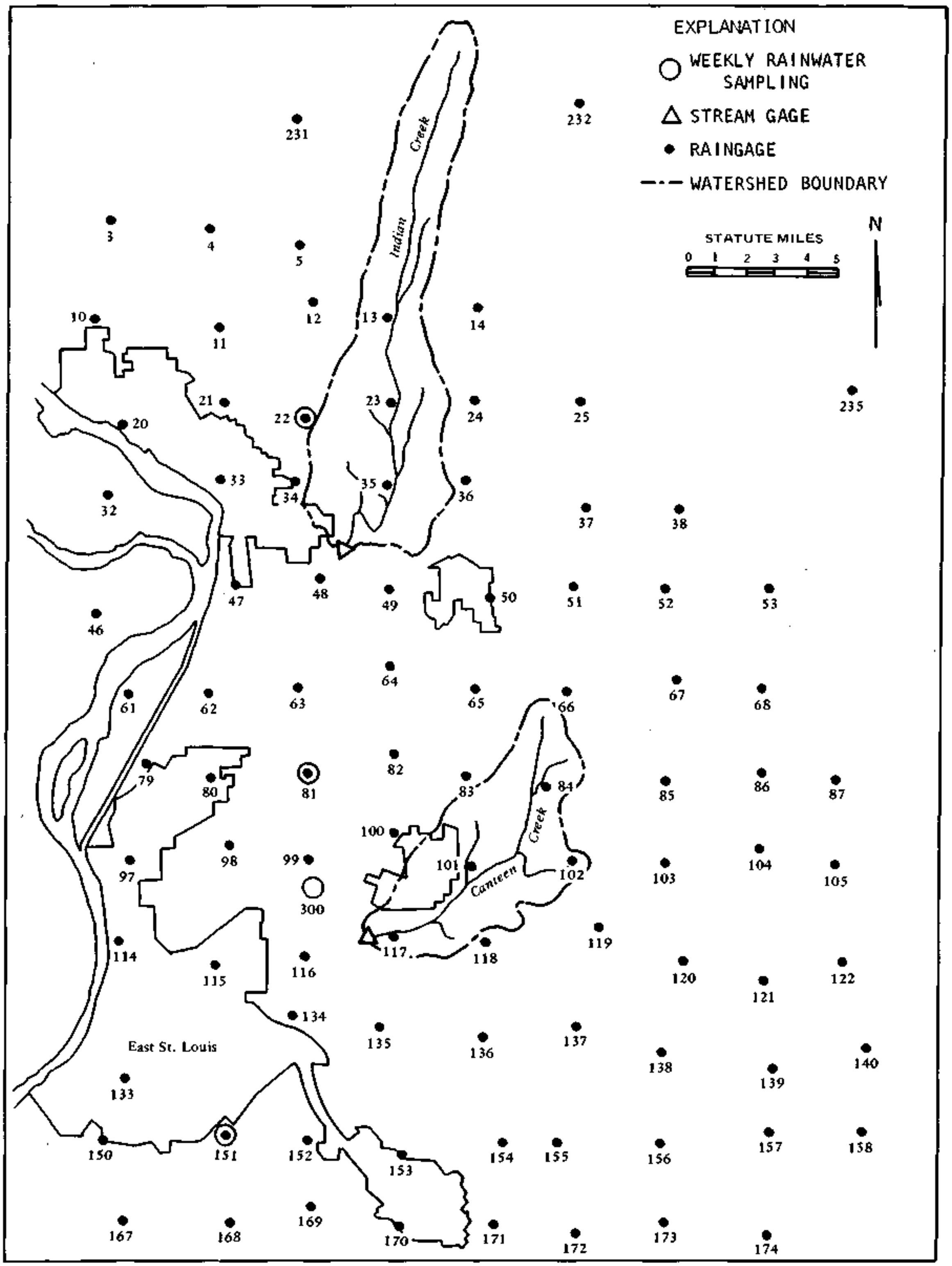

Figure M-1. Location of streamwater sampling basins and portion of METROMEX raingage network conditions. Although the test basins are small, many water supplies for small municipalities in Illinois are dependent upon impounding reservoirs with runoff from basins of this general size (Stall, 1964).

Examples of Preliminary Groundwater Results to Date

Table M-1 shows the relative magnitude of concentrations for various mineral constituents in groundwater samples from three large-capacity and one shallow well with those from a rainwater sample collected near the center of the study area. In general, the mineral concentrations in groundwater are considerably greater than in rainwater.

Table M-l. Mineral Analyses for Selected Samples
on July 31, 1973

Samples	Ca	Mg	Na	K	NO_3	Cl	SO_4	TDM*
			Concentration, mg/l					
Deep Well No. 1	59	16	8	3	16	10	64	303
Deep Well No. 2	142	37	14	5	2	24	165	644
Deep Well No. 3	142	35	27	31	31	85	194	730
Shallow Well	139	41	13	5	1-	37	169	664
Rainwater	4	1-	1-	1-	3	1	10	25

* TDM = Total Disolved Minerals

During the 2-week periods in June and September 1973 sufficient water levels in wells were measured to prepare piezometric surface maps. The maps were useful in showing the effects of the 1973 Mississippi River floods on groundwater levels. The high groundwater levels associated with the floods were one of the major factors in causing widespread sewer damage. Federal assistance had been available to communities in the area to aid in meeting costs of repairing and replacing damaged sewer lines. The groundwater level data was useful in preparing a report for the communities involved to ask for an extension of the termination date for federal assistance.

Examples of Preliminary Surface Water Analyses to Date

Data analyses have not yet progressed to the point where reliable conclusions can be made. Analyses of the weekly streamwater samples for summer 1973 indicate relatively strong relationship between the concentration of some chemical constituents in the surface water and antecedent rainfall, but weak correlations in other cases. Considerable variation in relationships. between the two streams also occurred during summer 1973. For example, a relatively strong correlation coefficient of -0.80 was obtained between total dissolved minerals and antecedent 24–hour rainfall on Canteen Creek. This lowered to -0.69 on Indian Creek. In general, the correlations between chemical constituents and antecedent rainfall were stronger on Canteen Creek than on Indian Creek. Results of the correlation analyses are summarized in Table M-2.

An indication of the concentration of the various chemical constituents in rainwater compared with those normally in streamwater is provided in Table M-3. In this table, the ratio of the average concentrations in rainwater to those in streamwater are shown for measurements made during June-August 1973. Except for nitrates and potassium, the concentrations in rainwater are very small compared with those in the streamwater on both basins. The relatively high rainwater concentrations of nitrates on both basins and potassium on Canteen Creek are not thoroughly understood at this time. Both of these chemicals are basic ingredients of fertilizers, and this suggests the possibility of surface dust blowing into the rainwater samplers (contamination) and/or ingestion of relatively large amounts of surface particulates into the convective rainstorms that dominate the summer rainfall. Huff (1964) found the ingestion process to be an important factor in the time distribution of rainout of radioactivity from convective storms. In any case, the high nitrate and potassium occurrences need further study.

A considerable portion of the streamwater analyses is dependent upon summer chemical data collected and analyzed by the METROMEX Project. As this information becomes available to us, more comprehensive analyses will be possible.

Table M-2. Correlation Coefficients Between Concentration of Chemical Constituents in Streamwater and Antecedent Rainfall, June-August 1973

Chemical Constituent mg/l	Correlation Coefficient for Given Antecedent Period			
	Canteen Creek		Indian Creek	
	24-hr	72-hr	24-hr	72-hr
Sulfates	-0.76	-0.81	-0.65	-0.64
Chlorides	-0.74	-0.82	-0.31	-0.26
Nitrates	-0.03	-0.17	0.38	0.46
Calcium	-0.82	-0.86	-0.70	-0.65
Magnesium	-0.85	-0.91	-0.78	-0.75
Sodium	-0.71	-0.79	-0.41	-0.37
Potassium	0.06	0.10	0.82	0.79
Total Dissolved Minerals	-0.80	-0.86	-0.69	-0.66

Table M-3. Ratio of Average Concentrations in Rainwater to Streamwater, June-August 1973

Chemical Constituent	Ratio for Given Basin and Constituent	
	Canteen Creek	Indian Creek
Sulfates	0.03	0.08
Nitrates	0.56	0.22
Chlorides	0.03	0.03
Calcium	0.10	0.04
Magnesium	0.02	0.01
Sodium	0.02	0.01-
Potassium	0.14	0.05
Total Dissolved Minerals	0.05	0.07

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N. GENERAL SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Seasonal and Storm Rainfall Studies

Seasonal rainfall was slightly above normal (103%) in 1973, compared with below-normal values of 63% and 69%, respectively, in 1971 and 1972. A major shift in the seasonal pattern occurred in 1973, in that the major high was recorded in the Granite City region, instead of near Edwardsville, and another regional high occurred at the western edge of the METROMEX Network. However, for the 3-summer period (1971-1973), total rainfall remained the heaviest near Edwardsville, and lowest rainfall was recorded west of St. Louis and the Mississippi River in a region that is usually upwind of any urban-induced effects on the precipitation. The 3-summer rainfall was over 30% greater than the network mean rainfall in the Edwardsville region, whereas the major low centers W and SW of St. Louis recorded approximately 75% of the network mean. The 1973 results have not reversed any of the trends observed in the 1971-1972 seasonal data, although slight changes in the location and intensity of some highs and lows occurred as a result of integration of the 1973 data into the sample.

Distribution of Heavy Rainstorms

The most frequent occurrence of storms producing one inch or more of rainfall remained in the Edwardsville area after three summers of operation. In this area, the 3-summer frequency has been twice the network average of six occurrences. This area is frequently downwind of either St. Louis or Alton-Wood River depending upon storm movements. Results continue to indicate that intensification of existing storms is a major cause of the seasonal highs which are most prominent east of the Mississippi River.

Weekday-Weekend Rainfall Relations

Analyses of 1971-1973 data provided evidence that the average frequency of rainfall per day is slightly greater on weekdays than on weekends in the immediate urban-industrial areas of St. Louis and Alton-Wood River. However, this effect does not appear to extend very far beyond the cities.

Diurnal Distribution of Summer Rainfall

Overall, more rainfall occurs in the late afternoon (1500-1800 CDT) than during any other period of the day. For 1971-1973, the network averaged 24.5% of its total summer rainfall in the 1500-1800 period. The most pronounced diurnal excess in this period occurred in the St. Louis urban-industrial area, including regions on both sides of the river, where nearly 40% of the rainfall, on the average, was recorded from 1500 to 1800. In general, findings were the same as in 1971-1972. The outstanding late afternoon maximum in the St. Louis region is likely related to intenifying of convection by a combination of natural diurnal heating and urban thermal-aerosol outputs. Conditions favorable for the development of convective activity in upwind feeder regions (Ozark foothills and river bottomlands) may also be involved in the positioning of the 1500-1800 rainfall maximum.

Synoptic Studies

Three major findings resulted from the synoptic analyses. First, over a third of the total rainstorms were associated with air mass conditions, but these storms produced less than 3% of the total rainfall for the 2-year period analyzed (1972-1973). Secondly, the more intense synoptic systems (squall lines, squall areas, and cold fronts) accounted for 89% of the total rainfall. Thus, it appears that the greatest potential for modification exists during the stronger, more intense synoptic events. Finally, the 1972-1973 analyses suggest that the more intense synoptic situations are primarily responsible for the maximum of rainfall in the downwind areas, and that air mass storms can not possibly account for substantial increases in rainfall as a result of urban modification, such as the 10% increase in areal rainfall in the St. Louis area found in earlier climatic studies.

Raincell Studies

Overall, the 1971-1973 results have provided strong evidence that the urban-industrial environment alter the precipitation regime. Increases in rainfall volume of cells with relatively short path lengths clearly indicate that volume increases are not simply the result of bias or chance sampling of long and heavy cells.

The precise causes of the urban-related precipitation increases are still not firmly established. It was found that the highest percentage increase in cell volume occurred in a heavy industrialized region within the city of St. Louis, which is a known source of Aitken nuclei. This suggests that micro-physical processes are an important factor in the rainfall increase. However, characteristics of cells in another highly industrialized area (Wood River) were somewhat different than those of cells in the industrial area of St. Louis. Furthermore, the St. Louis industrial area is also located in the vicinity of surface heat and moisture sources, and this suggests that dynamic influences are also important. Thus, it appears quite possible that both micro-physical and dynamic effects are involved in the precipitation increases in the urban-industrial areas. Additional studies of the raincell data in relation to warm and moist surface conditions are underway, and it is hopeful that these studies will provide additional insight into the effects of heat and moisture.

The most frequent initiation area for raincells was south and east of the St. Louis urban-industrial area, but another pronounced initiation area was located at Granite City. Initiation areas of lesser prominence were located at the bend in the Missouri River near Portage de Sioux, at Lambert Field, east of Wood River, and in Wood River-Edwardsville region. A striking feature of the cell initiation maps was the lack of significant initiation areas in the city of St. Louis. Most initiation areas were located close to the industrial sources of effluents with the exception of the prominent initiation area southeast of the industrial area of East St. Louis. This initiation area is in a position where it is likely to be subject to both topographic (Ozark Hills) and urban-industrial influences, depending upon the prevailing wind flow.

In all stratifications, the heaviest rainfall occurred during the maximum heating period, 1201-1800, and the lightest rainfall during the minimum heating period, 0001-0600. Results from 1971-1972 suggested a percentage increase in cell rainfall during the early morning hours when the heat island is well developed. However, the overall 1971-1973 results are only weakly indicative of such an increase.

An investigation of raincells with path lengths less than 12 miles indicated that the St. Louis and Wood River urban-effect cells were increased the most when convective activity was strongest. The increase in St. Louis cells was greater than in the Wood River cells which are exposed to a smaller urban-industrial area.

Most of the 1971-1973 cell rainfall occurred with squall areas and squall lines. The squall-area cells showed the largest percentage increase in the potential urban-effect cells at St. Louis. The squall-line cells were associated with the largest percentage increase in Wood River cells.

PPI Radar Echo Studies

Processed radar echo data for the 10-cm, FPS-18 radar were analyzed for 17 storm periods during the summers of 1972 and 1973. Results from this limited study indicated that rainfall is most likely to initiate south of Wood River in the vicinity of a group of oil refineries, and in the Ozark foothills, SW of St. Louis. Other relatively high initiation areas include the south central urban area of St. Louis, and scattered spots in the vicinity of Granite City, Collinsville, Edwardsville, and Alton-Wood River. Merger of echoes, frequently associated with the intensification of rainfall, occurred most often at the eastern and southeastern edges of the St. Louis urban area.

Comparison was made of the average properties of urban and non-urban echo intensity centers. Urban-effect echoes were found to have slightly longer durations (19 versus 15 minutes), path lengths (5.6 versus 4.3 miles), and maximum intensity 42 versus 37 dbz). Hill-effect storms had averages similar to the urban-effect storms, except their path length was longer

(6.9 versus 5.6 miles). These limited results from 17 storms suggest an urban effect, but also indicate that the topographic effects of the Ozark Hills in enhancing convective rainstorms may be similar in magnitude to the urban effect.

RHI First-Echo Study

Analyses were made of 170 first echoes on 8 days in August 1973. Results indicated distinct differences between formation frequencies with various land uses or land types. The urban areas, St. Louis and Alton-Wood River, had 50 to 70% more first echoes than the potential hill-effect and bottomlands-effect areas. The frequency per unit area of first echoes in the urban areas was over 100% greater than in the rural areas.

Regional differences were also found in the average tops and bases of first echoes. The average bases of first echoes were much lower over the urban and bottomlands regions than over rural areas. Synoptic variations were also found. Thus, first echoes were generally larger and higher in squall lines than in air mass storms. Also, differences were greater between urban and non-urban first echoes in air mass storms than in squall lines.

The similarity found in urban and bottomlands first echoes suggests they result from similar processes, achieving coalescence more rapidly above cloud base than occurs over rural areas. Overall, the RHI study results indicates that urban effects are instrumental in the precipitation process, and this is reflected in more initiations and lower cloud bases in the first echoes.

Thunder Data and Results

The number of thunder days in summer 1973 was similar, both in frequency and in pattern, to those in 1971-1972. Three new thunder stations were installed in 1973 to define better the eastward extent of the high found in the 1971-1972 data at Scott Air Force Base and Edwardsville. As a result, it now appears that the urban-related increase in thunderstorms is localized within an area of 1000 to 2000 mi^2. Synoptically, the 1973 results agreed closely with those for 1971-1972, and indicated that urban enhancement of thunder is most prevalent with cold frontal and air mass storms. Agreement was found also between the diurnal distribution of thunder in 1973 and 1971-1972. No appreciable regional differences occur in the 0300-1500 period, but increased activity is indicated east of St. Louis in the 1500-0300 period, with the greatest increase between 2100 and 0300 CDT.

Duration of thunder periods showed no systematic west-increase in 1973, and this differs from 1971-1972. Analysis of 1973 rates of thunder peals at six recorder sites showed a maximum at Edwardsville, and suggests that urban effects lead to more frequent electrical activity.

Hail Data and Results

Results show that 1973 experienced much more hail than 1971 or 1972. However, most 1973 results on hailstreaks, hail days, and hailfalls were quite similar to those for 1971-1972. The 1973 data provided further substantiation of previous conclusions that the St. Louis urban area produces sizeable increases in hail. The 1973 hail increases occurred mostly in late afternoon to mid-evening. As indicated in earlier publications, the typical urban-related hailstreak is larger, longer-lived, produces more hailstones, greater impact energy and is associated with more rain than those hailstreaks associated with non—effect cells. Synoptically, the 1973 results showed hail enhancement occurred most often in urban-effect storms with squall lines and cold fronts, in agreement with 1971-1972 results.

Surface Temperature, Moisture, and Wind Studies

Analyses of average air and dew point temperature for summer 1973 show the urban heat island in the St. Louis area decreasing from early morning to mid-afternoon. The center of the heat island under all sky conditions became enlongated and moved toward the east from morning to afternoon.

Under each of the sky conditions, there also was a tendency for the dew point temperature to maximize west of the city during the early morning in 1973. However, the afternoon maxima were located over the bottomlands (NW of St. Louis) and to the E and SE of the city. The bottomlands is one of the areas of preferred convective development determined in our METROMEX studies. The other maximum area has not been identified with any particular topographic or urban feature at this time.

An initial effort was made to determine the relationship between the warm and moist surface areas. Preliminary results reveal that there is an apparent relation between the localized warm and moist regions and the subsequent initiation of raincells and even heavier precipitation. Much more research is needed.

Analyses of average monthly winds in summer 1973 showed systematic regional differences within the 2100-mi^2 network on a monthly time scale. Similar results were obtained for summer 1972.

Boundary Layer Analyses

The airflow over the METROMEX region is perturbed by the city on both rain and fair days. This perturbation results in a zone of convergence over the city, extending through the first km. This implies net upward motion through cloud base level, enhanced moisture inflow, and transport of city effluents into cloud systems.

The wind measurements indicate significant reduction in speed downwind of the city at 500 m, and lowest average wind speeds directly above the urban area between 700 and 1200 m AGL. Enhanced vertical exhange of momentum and non-uniform flux divergence through the lowest one or two km is strongly suggested.

The various stability indices which have been devised as indicators of atmospheric potential for shower and thunderstorm development were not significantly nor consistently different at the urban station (Arch) than they were at the rural stations on rain days. The air tended to be a little warmer (about 1°C) and drier in the first km or two over the downtown St. Louis than over unaffected rural areas. In agreement with the higher temperatures and lower humidities, the lifting condensation level and the convective condensation level were higher over the city. The urban-rural differences in the latter agree well with differences in observed cloud base heights. The mixing depth also tended to be slightly higher over the city.

METROMEX Cloud Camera Studies

Analyses of cloud camera data for 1971-1973 from an installation in mid-city St. Louis indicated the greatest cloud initiation frequency was to the N and W of the site. The area of high frequency to the north of the site is located approximately five miles WSW of Granite City, which is a region of high raincell initiation. Therefore, it is quite possible that these cloud and raincell initiation regions are interrelated.

Hydrometeorological Analyses of METROMEX Raincell Data

Analyses are being made of potential urban effects upon heavy rainfall events of significance in urban hydrology applications, particularly in the design of storm sewer systems and related retention structures. Analyses of the 100 raincells with heaviest mean rainfall from the 1971-1972 sample of 1495 cells were made, and these supplemented with results of the study of 1-inch rainstorms. It was concluded that a major hydrologic implication is being brought forth by the METROMEX studies. Results indicate that rainfall rate frequency distributions may vary significantly between the urban, suburban, and rural areas in large urban-industrial regions. If further studies verify current findings, it may be necessary to re-evaluate storm parameters used in sewer design, so as to prevent underestimates of runoff relations in and downwind of these urban areas.

General Recommendations

During the remainder of the METROMEX field program, more attention should be given to studies of special breeding areas of convective activity. With installation of the new radar antenna system in 1975, a major effort should be made to use the FPS-18 radar in deriving more knowledge on echo development areas and the subsequent behavior and characteristics of urban and rural echoes. No further use should be made of the TPS-10 for analysis of urban effects, in view of the imminent capability of the FPS-18 to make sequential range-height observations.

Special efforts should be expended to study more thoroughly the relationship between surface hot-moist spots revealed by the hygrothermograph network and the initiation and possibly also the intensification of convective rainfall. Recent case studies have indicated that centers of relatively high air and dew point temperatures on the METROMEX Network frequently occur in conjunction with the initiation of raincells and radar echo intensity centers.

Recent case studies have also confirmed the need for more detailed cloud studies, including better monitoring of convective elements from the cloud stage to ultimate dissipation of associated raincells. For this purpose, cloud cameras, radar observations, continued raincell analyses, and SMS satellite data should be employed.

Analysis in the final two years of this METROMEX project should concentrate on both the climatic, all data evaluation approach, and on the case day study approach. Results of both approaches have shown they jointly shed more total information than either alone.

O. TRANSLATION OF RESULTS AND USERS OF PROJECT RESULTS

Stanley A. Changnon, Jr.

1. Utilizable Results

a. Presented first are the types of important project findings and presented upon request in 1973 only, to various persons, institutions, companies, or government agencies.

1) Findings on Severe Weather (Hail or Thunder) Changes Due to Urban-Industrial Effects

D. W. Hanby, Administrator, Nationwide Mutual Ins. Co., Columbus, Ohio
P. S. Brown, President, Hail Information Service, Ormond Beach, Fla.
E. Droessler, Dean of Research, N. C. State University, Durham, N.C.
B. Davis, Meteorologist, S. D. School of Mines £ Tech., Rapid City, S.D.
W. I. Shuran, Nestle Co., Granite City, Illinois
E. R. Fosse, Manager, Crop-Hail Insurance Actuarial, Chicago
S. Sheski, Student, University of Wisconsin, Madison, Wisconsin

2) Findings Showing Significant Impacts of Rain Changes on Planning, Agriculture, and Ecology

A. Mueller, Professor Agricultural Economics, Univ. of 111., Urbana
L. R. Koenig, RAND Corporation, California
D. M. Hershfield, Agricultural Research Service, USDA, Bethesda, Md.
G. Cox, Biology Department, Calif. State University, San Diego, Calif.
W. C. Hart, Biology Dept., Dalhousie University, Halifax, Nova Scotia
J. S. Maini, Program Coordinator, Environmental Concerns, Canadian Forestry Service, Ottawa, Canada
R. F. Paton, Planner, Du Page Regional Planning Commission, Wheaton, Ill.

3) Findings on Urban Effects on Temperature and Wind

P. Tompkins, Coordinator Directors Office, EPA, Research Triangle Park, North Carolina
R. Sutton, Illinois EPA, Granite City, Illinois
C. C. Paley, St. Louis County Health Department, Clayton, Missouri
G. E. Winzer, Office Secretary for Policy Development £ Research, HUD, Washington, D.C.

4) Findings on Urban Changes in Rain Quantity, Frequency, and Intensity

B. Atkinson, Professor, Queen Mary College, London
J. D. Goodridge, Climatologist, California Dept. of Water Resources, Sacramento, California
V. J. Schaefer, Atmospheric Scientist, State Univ. N. Y. , Albany, N.Y.

4) Findings on Urban Changes in Rain Quantity, Frequency 6 Intensity (cont.)

L. Helfand, Supervising Engineer, Illinois EPA, Springfield, Ill.
R. C. Stone, Federal Aviation Agency, Washington, D.C.
P. E. La Moreaux, State Geologist, State of Alabama, Birmingham, Ala.
D. L. Perossa, Executive Asst., Institute for Storm Research, Houston, Texas
W. T. Hodge, Chief, Users Services, NOAA, Washington, D.C.
M. Kohler, Hydrometeorological Branch, NOAA, Washington, D.C.
J. M. Bird, Environmental Modification Office, Washington, D.C.
M. Burnham, Hydraulics Branch, U. S. Corps of Engineers, St. Louis, Mo.
R. E. Coughlin, Vice President, Regional Science Research Institute, Philadelphia, Pa.
T. Weiss, Civil Engineering Department, Harza Engineering, Chicago, Ill.
R. L. Bloom, Meteorology Student, N. Y. University, Brooklyn, N.Y.
J. E. Pfander, Chemical Engineering Student, Univ. of Kentucky, Lexington, Ky.
B. Hanky, Director, East-West Gateway Coordination Council, St. Louis
R. W. Durrenburger, Professor, Univ. of Arizona, Tempe, Arizona
F. P. Rebello, Head Engineering Division, Brazil Institute of Aeronautics, Sao Paulo, Brazil
J. S. Adams, Research Director, University of Minnesota

5) Findings Supplied to News Media

W. McCann - Cleveland Plain Dealer - newspaper story
R. H. McLaughlin - W. Bath, Maine - magazine article
V. Boesen - Pacific Palisades, California - Book
N. Rodgers - Littlefield, Texas - magazine article
N. Calder - BBC, London, England - TV story
J. I. Mattill, Editor Technology Review - MIT, Cambridge, Ma. - magazine article
J. Shapiro, Reporter, Science in New England - Bringhton, Mass. - article

b. Data unique to the urban area were requested and utilized by many in 1973.

1) Scientists (staff and students) of other groups involved in METROMEX - Univ. of Chicago, Univ. of Wyoming, Argonne National Laboratory, Stanford Research Institute, and Sierra Nevada Corporation.

2) Scientists-at-large including 3 at EPA (wind data, temperature data, and cloud data); 2 at National Center for Atmospheric Research (rain), and one at U. S. Naval Academy.

3) Regulatory agency scientists
J. S. Kinsey, Air Quality Division, City Manager Office, Kansas City, Mo.
C. C. Paley, St. Louis County Health Dept., Clayton, Mo.

4) Business interests
W. I. Shuran, Nestle Co. Inc. , Granite City, Illinois
M. Brewer, Zurheide-Herman Engineers, St. Louis, Missouri

c. Software and Hardware Developments

1) Instruments to monitor thunderstorms were invented, constructed and operated. They automatically record thunder and permit a directional analysis to identify which rainstorms are thunderstorms, a useful meteorological research instrument.

2) Developed a series of computer programs using digital rainfall data from 250 raingages to determine individual storms or show cells in complex arrays of convective entities.

3) Developed a series of computer programs to process radar weather echo digital data so as to calculate a variety of discriminate 2-dimensional portrayals of echoes.

d. Miscellaneous - Films and Significant Results - Data

1) Furnished radar film (especially-developed sequence) to BBC for Science Special "The Weather Machine".

2) Certain results have great general use in the atmospheric sciences and in planned weather modification specifically. These include strong proof that urban factors lead 1) to 5 to 30% increases in summer rain; 2) 10 to 100% increases in hail frequency and intensity; 3) 20 to 30% increases in thunderstorm frequencies; and 4) 50 to 80% increases in intense rainstorms.

3) An important analytical technique and concept useable in the atmospheric sciences developed in this project concerns statistical definition of individual convective raincells.

4) A major utilizable result of this project is a 3-year data bank containing unique never-before-collected, urban area weather data. These include 3-year records of hourly rainfall from 225 raingages, hailfalls at 200 hail sensors, continuous temperature and humidity records at 30 weather stations, and low-level wind flow from pilot balloon observations on many days.

2. The Users - Who and When

These have been identified in detail for 1973 in Section 1 above. However, summarization pf users reveals the major interests and the types of users.

The major interests reflect in users include:

a. Urban increases in hail have brought forth use of information by hail insurance industry in proper rate setting downwind of cities.

b. Management and planning of hydrologic systems due to more rain and more frequent intense rainfalls.

c. General urban planning.

d. Use of findings in scientific research dealing with air pollution, local (urban) weather forecasting, agriculture, ecology, planned weather modification, and inadvertent climatic change.

e. Concern over air pollution, planning for its management, new measurement programs and regulation.

The users reflected in the 52 requests received in 1973 for project results, information, and data have been classified by their organizations.

New media	7
Commercial firms	5
Industries	2
Universities	14
Research Institutes - Laboratories	6
Local and State Governments	7
Federal Agencies	9
Foreign Governments	2

3. <u>Relationships with Users</u>

We have established many relationships with users, and those with continuing interests have been maintained in a variety of ways. An example of a user responding to one of many announcements of our published results as shown in attached letter from Alabama.

These user relationships have included a) wide (and free) distribution of published scientific papers and reports; b) many oral presentations to a wide variety of audiences (see below); c) talks (radio and TV) and articles for the news media (see below); d) considerable correspondence; and e) extensive telephone conversations (long distance costs in 1973 - $2000).

a. <u>Project Talks Given in 1973-1974 Period - Listed on next page</u>.

b. <u>News Stories and Magazine Articles</u> - Listed on page

4. <u>Impacts of Results</u>

a) The existence, operations, and results of this project have had major impacts on the program policy, planning, and design for the Regional Air Pollution Study (RAPS), a major national program of EPA designed to study influence of weather on air pollution (the inverse of this project). RAPS will be centered at St. Louis, and the decisions to initiate RAPS and to locate it at St. Louis are founded on the successful establishment and conduct of this project (METROMEX). This project has provided information of sites, local contracts, and much temperature, cloud, and wind data to EPA.

a. Project Talks Given in November 1972-September 1974 Period

Title	Where	Audience Type	Audience Number	When
Man's Weather Alterations	Ill. Society of Civil Eng.	Engineers	50	November 1972
Urbana Weather Effects	N. C. Science Lecture Series	Scientists	70	December 1972
Water Survey's METROMEX Results	Air Pollution Seminar, EPA	Meteorologists	30	December 1972
Results of METROMEX	Annual Meeting AMS	Meteorologists	130	January 1973
Water Survey's METROMEX Results to Date	Chicago Chapter AMS	Meteorologists	50	February 1973
METROMEX and You	St. Louis Chapter of AMS	Meteorologists	35	February 1973
METROMEX Results and Operations	TV Channel 15, Champaign, IL	Public	120,000	March 1973
METROMEX Update	C-U Exchange Club	Businessmen	100	March 1973
Ecological Impacts of Urban Weather Changes	Workshop on Urban Ecology	Biologists	40	March 1973
Results of METROMEX	Joint Soviet-USA Exchange	Scientists	20	May 1973
Airflow over St. Louis	Annual Meeting of Air Pollution Control Association	Air Pollution Science	200	July 1973
METROMEX Progress	Interview-KMOX-TV Station St. Louis	Public	850,000	July 1973
Urban—Industrial Effects on Clouds and Precipitation	Inadvertent Weather Modification Workshop at Utah State	Engineers	30	August 1973
METROMEX and the Water Survey Programs	Annual Meeting of WMA	Government ε Meteorologists	75	September 1973
METROMEX and Your Environment	Honors Seminar on Environment	Ecologists	120	September 1973
Urban Rain Changes	Midwest Groundwater Conf.	Hydrologists	200	October 1973
Enhancement of Severe Weather at St. Louis	AMS Severe Storms Conference	Meteorologists	150	October 1973
Secular Changes in Thunderstorms	AMS Severe Storms Conference	Meteorologists	150	October 1973

a. Project Talks Given in November 1972--September 1974 Period (cont.)

Title	Where	Audience Type	Audience Number	When
Inadvertent Weather Modification	Taped 30-min. interview, Public Educational Radio System	Public	1.5 Million	November 1973
METROMEX: Some Preliminary Results	St. Louis Branch AGU	Geophysicists	50	December 1973
Do Urban Produced Rain Changes Have Significant Impacts?	Annual Meeting of AMS	Meteorologists	55	January 1974
Analysis of Urban-Effect Thunderstorm	AMS Conference on Weather Forecasting	Meteorologists	125	March 1974
Inadvertent Weather Modification Progress and Problems	Annual Meeting of Weather Modification Association	Scientists	75	March 1974
Report on METROMEX Findings	Spring Meeting of METROMEX Scientists	Scientists	40	April 1974
The Reality and Impact of Urban Weather Changes	Lecture at Southern Illinois University	Scientists	60	May 1974
Research Priorities for Inadvertent and Planned Weather Modification	Conference of States on Weather Modification	Administrators, Scientists, Politicians	150	June 1974
METROMEX: Its Goals and Activities	Paper at St. Louis Annual Meeting of Regional Air Pollution Studies Program	Scientists, Engineers	125	July 1974
Hydrologic Aspects of Urban-Induced Heavy Rains	Paper at Conference in Urban Rainfall and Runoff	Engineers	150	July 1974
Urban Meteorology and METROMEX	Rotary Club Danville	Businessmen	100	August 1974
Secular Changes in Thunderstorms	Paper at International Conf. on Atmospheric Electricity	Scientists	200	September 1974
Impacts from Urban-Induced Precipitation	Paper at Earth Environment and Resources Conference	Scientists, Engineers	25	September 1974

a. Project Talks Given in November 1972-September 1974 Period (cont.)

Title	Where	Audience		When
		Type	Number	
The Cutting Edge of Inadvertent and Intentional Weather Modification	Lecture at Retreat for Senior IBM Staff	Engineers	50	September 1974
The Hydro-Climatic Aspects of Rainfall Changes at St. Louis	AMS Conference on Climatology	Scientists	95	October 1974
Wind Profiles and Their Variability in the Planetary Boundary Layer	AMS Conference on Air Pollution and Diffusion	Scientists	125	September 1974

b. News Stories and Magazine Articles

Title	Source	Date of Release
St. Louis to be Center for Air Pollution Study	AP Nationwide Story	November 1972
Widespread Weather Modification on Horizon	Conservation Foundation	January 1973
Memphis Makes Weather	Mid South Magazine Commercial Appeal	February 1973
Last Summer's Rain Heaviest Noted	Belleville, Illinois	March 1973
Urban Atmosphere Bears on Weather	Kansas City Star	March 1973
La Porte Phenomenon - Unplanned Weather Modification	Outdoor Indiana	April 1973
Weather Monitored Downwind from St. Louis	Kansas City Star	July 1973
Listening for Rain	AP Regional Wirephoto	July 1973
They Stole Our Rain	Vista Magazine	August 1973
Don't Mess with Mother Nature	Science £ Mechanics	August 1973
Sun Plus Pollution Lower Light Level	Industrial Research	October 1973
Rain, Snow Studies Grow	Everyday Magazine, St. Louis Post Dispatch	October 1973
We're Changing the Weather by Accident	Science Digest	December 1973
METROMEX and Urban Rain	Univ. of Ill. News Service to State Newspapers	January 1974
City Causes Wetter Weather	UPI National Release	January 1974
Hail in Illinois - City Effects	State Release	March 1974

4. Impacts of Results (cont.)

b) The crop-hail insurance industry has 1) altered its rate structure (see excerpts in attached letter) downwind of St. Louis, and 2) has begun incorporating rate increases downwind of several major cities.

c) The Illinois Environmental Protection Agency will utilize project rain results in setting State regulations in the design of sewer systems.

d) The Illinois State Water Survey has been influenced by the results and has initiated a 2-year program of water (surface and groundwater) quality study in the project area.

e) The project results are being used by the Atomic Energy Commission as part of their immediate studies of precipitation scavenging of pollutants. These results are part of a regulation-setting process concerning AEC power plant siting.

5. Benefits from Results

The major impacts of the findings of this project are as inputs into complicated systems, often involving future planning. Hence, it is very difficult, and has not been a part of this project, to have users specify the exact economical value of the product. In fact, it may be very difficult for them to assess what the monetary value of one segment of information is in a complicated system such as insurance rating. The crop-insurance industry in Illinois alone has a $30 million income from Illinois farmers and a better assessment of loss and rating around the State's major urban areas represents potential savings to the farmers and to the industry. It certainly reflects on a more justifiable uniform support of costs and sharing of losses.

The savings to be gained through less damage from improved sewer system designs based on the project's rainfall results can not be specified, but as an included letter states, billions of dollars in Illinois will be spent on these systems in the next decade, and project results are being used to develop regulations and design criteria for these systems. It will certainly lend to less damage from water and pollution.

Another way of at least suggesting some of the general economic values of the project findings are the contents of 3 attached letters and a copy of a portion of a recent news release by the Crop Insurance Research Bureau. These demonstrate the impact and value of the findings, in the words of users.

The major benefits of many of the project results relate 1) to improving the way of life of both urban and rural citizens, 2) to the more efficient operations of weather-related businesses, and 3) to more accurate knowledge and more realistic regulations for local, state, and federal agencies dealing with urban areas, agriculture, and water resources.

6. Publications and Their Distribution

The potential number of readers of the 25 scientific papers (as based on the circulation of the journals) is 120,000. In addition, 400 copies of each were distributed to the scientific community in the Survey's annual volumes of reprints.

The readership of the news articles concerning the project was about 70 million, and this coupled with potential radio-TV audiences for our media presentations, plus readers of papers and reports, resulted in an estimated 75 million persons who were conceivably reached with information about

METROMEX in 1973-1974. Thus, nearly 1 out of every 3 Americans had potential exposure.

The list of project publications since the METROMEX inception in 1971 under GA-28189X, then under GI-33371 in 1972, and as GI-38317 in 1973-1974 follows.

PUBLICATIONS

Scientific Papers Generated

1. Inadvertent Rain Modification as Revealed by Rain Cells (PTS), *J. Applied Meteorology*, 1974
2. Climatological Assessment of Extra-Area Seeding Effects (PTS), *J. of Weather Modification*, 1974
3. Airflow Over the Metropolitan Area of St. Louis (BA), *J. of Air Pollution Control Assoc*, 1974
4. Precipitation Modification by Major Urban Areas (FAH-SAC), *Bulletin, AMS*, 1973
5. The Raincell Approach to the Evaluation of Rain Modification Effects (PTS), *Reprints 3rd AMS Conf. of Weather Modification*, 1972
6. Atmospheric Alterations from Man-Made Biospheric Changes (SAC), *Modifying the Weather*, 1973
7. Secular Trends in Thunderstorm Frequencies (SAC), *Preprints AMS Conf. on Severe Storms*, 1973
8. Enhancement of Severe Weather by the St. Louis Urban-Industrial Complex (SAC-FAH), *Preprints AMS Conference on Severe Storms*, 1973
9. A Statistical Approach to Computerized Rainfall Patterns (PTS), *Preprints Conf. on Statistics and Probability*, 1973
10. Inadvertent Weather and Precipitation Modification by Urbanization (SAC), *J. Irrigation S Drainage Division ASCE*, 1973
11. Analysis of Possible Urban-Effected Thunderstorms (JV), *Preprints Analysis £ Forecast Conf.*, 1974
12. Climatological Assessment of Urban Effects on Precipitation at St. Louis (FAH-SAC), *J. Applied Meteorology*, 1972
13. Results of METROMEX (SAC, RGS, WL), *Preprints Conference on Urban Environments*, 1972
14. Urban Effects on Thunderstorm and Hailstorm Frequencies (SAC), *Prep. Conf. on Urban Environments*, 1972
15. Winds in the Ekman Layer over St. Louis (BA), *Preprints Conference on Urban Environments*, 1972
16. Synoptic Analyses of Summer Rainfall Periods Exhibiting Urban Effects (GM, RB), *Preprints Conf. on Urban Environments*, 1972
17. Can Weather Modification Usefully Augment the Water Resources of the Humid Midwestern United States? (SAC), *Proc. International Symposium on Water Resources*, 1972

Scientific Papers Generated (cont.)

18. Inadvertent Precipitation Modification by Urban Areas (FAH-SAC), *Preprints 3rd Conf. of Weather Modification*, 1972
19. METROMEX: Summary of Results (RGS-SAC), *Bulletin, AMS*, 1974
20. METROMEX: An Overview of Illinois State Water Survey Project (SAC), *Bulletin, AMS*, 1974
21. METROMEX: Rainfall Analyses (FAH-PTS), *Bulletin, AMS*, 1974
22. METROMEX: Wind Fields over St. Louis in Undisturbed Weather (BA), *Bulletin, AMS*, 1974
23. Wind Profiles and Their Variability in the Planetary Boundary Layer (BA), *Preprints Conference on Air Pollution*, AMS, 1974
24. Urban-Industrial Effects on Clouds and Precipitation (SAC), Proc. *Workshop on Inadvertent Weather Modification*, 1973
25. Agricultural and Water Resource Impacts from Urban-Induced Precipitation Changes (SAC), *Digest of Technical Papers-Earth Environment and Resources Conference*, 1974

Reports

1. *1971 Operation Report for METROMEX* (SAC), Illinois State Water Report, 1972
2. *Study of Urban Effects on Precipitation and Severe Weather at St. Louis* (SAC), Annual Report to NSF, Illinois State Water Survey, 1973
3. *Summary Report of METROMEX Studies, 1971-1972* (FAH), Report of Investigation 74, Illinois State Water Survey, 1973

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

2200 Churchill Road
62706

Springfield, Illinois
Phone: 217/525-2027

November 2, 1973

Stanley A. Changnon, Jr., Head
Atmospheric Sciences Section
Illinois State Water Survey
Water Resources Building
Champaign, Illinois

Dear Stan:

I have received a copy of Report of Investigation #74 "Summary Report of Metromex Studies", for which much thanks. As you know I have been interested in the question of whether such studies as you are conducting and have reported on could be specifically utilized in sewer system design and/or the correction of the large number of recurring sewer system surcharges. The "ramcell and thunderstorm occurrences which are defined and discussed in the Summary Report are of enormous consequence in that they appear to trigger the sewerage treatment works bypassing, the basement inundation, and the sewers system overflows, on which problems it is proposed some hundreds of millions or billions of dollars be spent in Illinois alone in the next decade.

In this regard I have several questions that hopefully are pertinent to the practical utilization of the Metromex studies; doubtless each question will evolve into many others.

1. Have you been able to determine a preferred orientation of cells in multicell thunderstorm; that is cells in rank or in file? Does this, if determinable, depend on whether the storm is stationary or moving?

2. Is there a minimum (average) distance (or time) between heavy precipitation occurrences in a multi-cell storm?

3. Is the period of intense rainfall due to the cellular structure of a storm (in the mid-west late spring) of 5-minute, 10-minute, 20-minute duration, or some other definable brief period? Is it advisable to change the data base to a period other than one hour or one day?

4. What is the best placement position for a sewage works with regard to storm flow?

The enumeration of possible questions can be vastly increased, yet apparently all would be of value in the determination of the ultimate sewer design problem, which is to locate and size piping to provide for least magnitude and least harmful incorporation and transport of unwanted storm waters in sanitary or combined sewer systems.

The recent adoption by the Illinois Pollution Control Board of regulations for regionalized sewage treatment works with extensive collection systems (for DuPage County), and the proposal that regionalization be expanded into Lake and other counties, may provide occasions for emphasis as to the need for incorporation of the precipitation patterns in the control and proper treatment of liquid wastes.

With best regards,

Sincerely,

Leo Helfand

Leo Helfand, Supervisor
Engineering Advisory Unit
Enforcement Services Section
Division of Water Pollution Control

LH/mw

ATTCH. A-2

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ASSISTANT SECRETARY

April 16, 1973

Mr. Stanley A. Changnon, Jr., Head
Atmospheric Sciences Section
Illinois State Water Survey
Water Resources Building
Box 232
Urbana, Illinois 61801

Dear Stan:

I,took for train and leisure reading both your St. Louis initial text and the 12.21.72 final report on the hail network studies. From the latter I was struck by your "single word best describing - variability" reference, which has a major application to my tentative analysis of the annual yield data.

The St. Louis project has much to say for the thoroughness of your research and as a casual but interested observe I am impressed by the results you describe. While for some the period studied may be more limited than would be preferred, there seems little on which there could be based a question about the general conclusion: There <u>is</u> an effect of large industrial/metropolitan areas on at least certain aspects of hail occurence.

You note and exhibit the confirmative comparison of the loss cost data, and herein lies the use - value to the Association and the companies. As you know, our statistics are relatively inadequate in the southern 1/3 of Illinois. Your findings certainly serve to confirm the judgment value of those statistics; at this point I would tend to attach greater credibility to your filings than to the limited data we have for St. Clair County.

Furthermore, while I think of none presently, it is conceivable there are other areas to which we could make reasonable application of the concept, after identifying the peripheral area and directional information needed.

At this point I do not think of further information which would be useful to us. I am making a distribution of the report to selected company people, asking for their comment. I will respond further if I catch any suggestions.

ATTCH. B

Yours very truly,

ERF/so

E.Ray Fosse, Manager

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
ST. LOUIS DISTRICT, CORPS OF ENGINEERS
210 NORTH 12TH STREET
ST. LOUIS, MISSOURI 63101

IN REPLY REFER TO

LMSED-HG

13 February 1974

Mr. Stanley A. Changnon, Jr.
Head, Atmospheric Sciences Section
Box 232
Water Resources Building
605 East Springfield
Urbana, Illinois 61801

Dear Mr. Changnon:

I would like to express my appreciation for the assistance and information furnished Mr. Michael Burnham of my office concerning the effects of urbanization on precipitation. We feel the data in the Illinois State Water Survey's "Summary Report of Metromex Studies 1971 and 1972", and your paper entitled "Inadvertent Weather and Precipitation Modification by Urbanization", are important to the St. Louis District's East St. Louis and vicinity, Illinois, and seven county Metro St. Louis area studies.

We also feel the continuation of the "Metromex" study is important in the hydrologic analysis of these studies and would appreciate any additional information, assistance, and comments, you may have on the subject.

Sincerely yours,

James T. Lovelace

JAMES T. LOVEIACE
Chief, Hydraulics Branch

ATTCH. C

Changnon

From GEORGE THIEM, Manager
Crop Insurance Research Bureau,
1856 Sherman Avenue,
Evanston, Illinois 60201
Tel. 312-328-5206

For release Wednesday,
Feb. 27, 1974 newspapers

NOTE TO EDITOR: This story has special interest, we believe, for its analysis and detail about a weather phenomenon in Illinois last year ---- hailstorms.

Mailed to 480 Ill. newspapers Sat. AM. 2/23
also St Louis dailies, but Iowa [illegible] Gazette edited this
dailies. Times A.M. (2/25) will feature in
release in Farm Edition Mar. 17, 74
G.T.

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of $40 millions, George Thiem, manager of Crop Insurance Research Bureau, reported today.

Largest loss payment of record in excess of $59,000 went to a Madison County soybean and wheat grower, Ralph G. Buske of Granite City, following: a destructive August 12 hailstorm. A neighbor lost his entire crop' - 350 acres of soybeans - and collected $52,500 from his insurer.

"It hit us about 3 p.m. and came from the southwest", said Buske, a tenant on a fertile 892-acre farm. "It began with rain, then marble-sized hail and finally chunks of mixed ice and snow up to hen's egg size came down. Gusts of 40-mile an hour wind made it worse."

The storm covered an area about a mile and a half wide and several miles long, Buske said "But our 100-acre field a mile north got no hail and not a drop of rain. That's the way these storms are. It was all over in 25 minutes."

Granite City is an industrial area. Meterologists thirkair pollution with its dust particles increases the volume of hailstone formation.

Changnon of the State Water Survey said air pollution in industrial areas such as Chicago and St. Louis stimulates hail formation. Hail is known to require nuclei or seed, he explained, for a hailstone to start its growth. Hailstones initiate in below freezing areas. They must have access to super-cooled water and swift intermittent upward air movements to freezing temperatures to gain size. However, hailstorms are produced under a wide variety of weather — warm fronts, cold fronts or in isolated thunderstorms.

ATTCH. D-1

Hail fell somewhere in the Survey's 2,000 square mile network centering at St." Louis on 19 days during the June-August study period. Changnon cited the devastating August 12-13 storms in the E. St. Louis area as the worst of the summer.

"Spectacular hail with irregular pieces of ice up to two inches in diameter, fell on August 12 for 25 minutes," he said. The following day the storm was most intense just east of St. Louis. It produced a heavy fall of one-inch stones. Our hail-gauge measured 624 hailstones in a one-foot square area within five minutes."

Damaging hailstorms hit the Chicago area on June 18 and June 23 destroying soybeans and injuring corn fields south of Naperville at the DuPage-Will county line. The rich farming area is due west of the South Chicago-Indiana industrial complex.

One company paid 20 hail claims there for $165,000. Keller Brothers and George W. Grommon had some 700 acres of soybeans and corn in the direct path of the storm. Eighty-five per cent of the Keller's 195-acre soybean crop was wiped out. Hail ruined 105 acres of soybeans on the Grommon farm. The corn crop was scarcely damaged. Settlement was based on the reduced yield after the harvest.

GEOLOGICAL SURVEY OF ALABAMA

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FEBRUARY 4, 1974

ILLINOIS STATE WATER SURVEY
P. O. Box 232
URBANA, ILLINOIS 61801

DEAR SIRS:

IN THE JANUARY 22 WATER NEWSLETTER A REFERENCE WAS MADE TO REPORT OF INVESTIGATION 74 OF THE ILLINOIS STATE WATER SURVEY CONTAINING PROOF OF WEATHER CHANGES DOWNWIND OF URBAN AND INDUSTRIAL AREAS.

FOR MANY YEARS THIS HAS BEEN A QUESTION THAT HAS CONCERNED US IN OUR RESEARCH WORK ON WATER IN ALABAMA, AND I WOULD LIKE TO OBTAIN A COPY OF THE REPORT FOR OUR FILES.

CONGRATULATIONS ON CARRYING OUT AN EXTREMELY INTERESTING RESEARCH EFFORT ON WEATHER AND ENVIRONMENTAL CHANGES.

BEST REGARDS.

Sent
2/7/74

SINCERELY YOURS,

PHILIP E. LAMOREAUX
STATE GEOLOGIST
OIL AND GAS SUPERVISOR

COPY TO MRS. DOROTHY BRADY, LIBRARIAN

ATTCH. E