METROMEX: an investigation of inadvertent weather modification

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Abstract

METROMEX, a field project designed and now in progress at St. Louis, involves 4 research groups planning and working cooperatively to study inadvertent weather modification by urban-industrial effects, and, in particular, man-made changes of precipitation. Urban areas affect most forms of weather and some, such as winds, temperature, and visibility, are obvious and their changes are easily measured. Inadvertent precipitation changes are harder to measure, and except for the well-documented La Porte anomaly, urban-related rain changes have had only limited study. Examination of historical data at St. Louis has revealed summer increases in the immediate downwind area of: 1) rainfall (10–17%); 2) moderate rain days (11–23%); 3) heavy rainstorms (80%); 4) thunderstorms (21%); and 5) hailstorms (30%). METROMEX field measurements in the summer of 1971 involved 220 raingages and hailpads, 3 radar sets, 70 rainwater collectors, 14 pibal stations, 4 meteorological aircraft, unique atmospheric tracers, and a wide variety of standard and unusual meteorological equipment. These measurement tools were used to provide information on 1) the processes of cloud and precipitation formation, 2) the chemistry of aerosols and rainwater, 3) the urban heat budget, 4) the 3-D patterns of precipitation elements, and 5) the airflow and cloud development for numerical models.

1. Introduction

Scientists from the Argonne National Laboratory, University of Chicago, Illinois State Water Survey, and University of Wyoming have begun a cooperative scientific program to study the inadvertent modification of weather by an urban-industrial complex. Emphasis is on the study of urban-related alterations in precipitation processes and quantitative changes in surface precipitation.

Consideration of the available climatological data, available resources, and the location of the research groups resulted in the choice of the St. Louis area as the site of the field project of METROMEX (which stands for METROpolitan Meteorological EXperiment). The field project is the major effort of METROMEX, but it also involves laboratory and atmospheric modeling projects. The first field operations and data collection for METROMEX occurred in the summer (June–August) of 1971.

The general program goals are 1) to study the effects of urban environments upon the frequency, amount, intensity, and duration of precipitation and related severe weather; 2) to identify the physical processes of the atmosphere which are responsible for producing the observed urban weather effects; 3) to isolate the factors of the city complex which are the causative agents of the observed effects; and 4) to assess the impact of urban-induced inadvertent weather changes upon the wider issues of society.

The purpose of this paper is to describe the background and basis for METROMEX, the organizational aspects of the program, and the activities of the four research groups involved in METROMEX. The program background includes a general review of urban-related weather modification and a description of urban-related precipitation changes illustrated by examples for St. Louis. The organizational aspects of the program include the research plans, the physical organization, and the program management. In the final section, the goals, plans, and field measurements of each group are described.

2. Background

Man has suffered the excesses and enjoyed the pleasures of weather throughout his existence on Earth, but it has only been in the last 150 years that he has begun to affect the weather significantly. Although man for many centuries has speculated on his effect on weather through such activities as major battles, incantations, large fires, and atomic explosions, the major means whereby he has affected weather has been inadvertent and through his urban-industrial environment. More than 700 years ago the London urban complex had achieved a size such that it produced a recognizable effect on its local weather, at least in terms of reduced visibility and increased temperature (Chandler, 1970). Serious scientific attempts by man to modify weather have been confined to the last 25 years, and have been limited to a few localized projects indicating precipitation increases (and decreases) and fog dissipation. His intentional efforts have yet to produce major, widespread changes.

The increase in urbanization that began 200 years ago with the Industrial Revolution has led to certain significant microscale and mesoscale changes in the weather and climate in and near urban locales in the mid-latitudes (Peterson, 1969). Considerable scientific attention has been directed to this urban problem in the European area during the last 100 years (Kratzer, 1956). As major urban-industrial complexes became prevalent in many countries, worldwide attention to this problem developed rapidly in the last 20 years. Furthermore, the development of megalopolises in the United States during the past 10 to 30 years has brought with it increasing public and scientific awareness of the existence and, in some cases, the seriousness of urban effects on weather.

a) General effects of urban areas on weather

What are urban effects on weather? The changes wrought by urbanization include most major surface weather conditions. They may be categorized according to two classes: the *obvious,* or easy to measure, and the *subtle,* or hard to measure. The more obvious effects of urban areas on weather include such things as decreased visibility resulting from contaminants in the air, reduced winds, and increased air temperature.

Certainly, many are aware that in a major complex the visibility is more frequently restricted than in rural areas. Smog is now a household word. Most Americans also are aware that the temperature within a moderate to large sized urban area is generally higher at any given time than it is in nearby rural areas. The temperature effect has been well recognized and reasonably well measured for many years because its direct measurement, at least at the surface, is easily accomplished. Thus, "heat islands" in various sizes of cities have been quite well documented. Also, it is generally acknowledged that urban areas act as an obstacle to decrease winds near the surface, to increase turbulence and vertical motions in the atmosphere above cities, and to create occasionally a localized rural-urban circulation pattern.

The more subtle, less recognized weather changes wrought by urban areas include alterations of fogginess (as opposed to smog), cloudiness, rainfall, snowfall, solar radiation, humidity, atmospheric electricity, severe weather events (such as thunderstorms, hail, severe rainstorms), and certain mesoscale synoptic weather features. There have been sufficient descriptive studies to reveal that these more difficult to measure weather conditions are being changed, sometimes dramatically, by urban complexes.

The degree of change in any of these weather elements at any time is dependent upon various factors. Some of these are the areal extent of the urban complex, the components of the industrial complex, its juxtaposition to major water bodies and other topographic features, time of day, season of year, existing weather conditions, and climate. The degrees of change reported at various American and European cities have been compiled (Landsberg, 1962), and used to develop the average percentage changes (urban vs. rural) shown in Table 1.

Naturally, large variations from these averages can occur for a given month, day, or hour. For instance, urban solar radiation is decreased much more in winter than in summer. As shown in Table 1, urban air temperatures in winter average approximately 2F higher than in the surrounding rural areas, whereas in summer they average only about 1F higher. However, the diurnal variation of the urban-rural difference is particularly pronounced, and under favorable weather conditions, the difference may exceed 10F a few hours after sunset (Kratzer, 1956).

TABLE 1. Worldwide data showing average changes expressed as per cent of rural conditions.

	Annual	Cold season	Warm season
Contaminants	+1000	+2000	+500
Solar radiation	−22	−34	−20
* Temperature (°F)	+1.5	+2.0	+1.0
Humidity	−6	−2	−8
Visibility	−26	−34	−17
Fog	+60	+100	+30
Wind speed	−25	−20	−30
Cloudiness	+8	+5	+10
Rainfall	+11	+13	+11
Snowfall	±10	±10	—
Thunderstorms	+8	+5	+17

* Percentages not applicable.

It should be realized that opposite changes in certain weather conditions are produced at different times. For example, fog is generally increased by urbanization, although certain types of fogs are actually dissipated in large cities (Landsberg, 1956). Snowfall can be increased by urban areas, but in certain weather conditions the city heat actually melts descending snow, transforming it into rain.

b) Urban-related precipitation changes

Several German and English studies of the 20th century were concerned with added cloudiness, precipitation, and severe weather within and downwind of certain cities (Ashworth, 1929; Kratzer, 1956). However, modification of precipitation conditions in the United States through inadvertent urban-related processes was not noted until the 1950's when Landsberg (1956) presented indications of urban-produced rain increases at Tulsa. Some of the primary reasons for the lack of awareness and study of this subject were a general lack of climatological expertise in the United States, and, more importantly, the lack of weather station networks adequate for measuring small-scale precipitation changes and defining other mesosynoptic weather conditions. Thus, the rather localized nature of the precipitation changes easily went undetected.

The Illinois State Water Survey initiated studies of possible urban-industrial effects on precipitation processes in 1958 with the study of two middle-sized urban areas in Central Illinois (Pearson, 1958; Changnon, 1962). Further climatological investigations in the early 1960's revealed a startling increase in precipitation 30 miles downwind of the Chicago-Gary area at La Porte, Ind. (Stout, 1962).

All of the precipitation-related conditions at La Porte underwent thorough study in the 1965–1967 period (Changnon, 1968). This study revealed rather significant warm season increases in total precipitation and in the frequency of rain days, thunderstorm days, and hail days.

The La Porte results met with considerable national interest, both in the scientific community and by the general public. Scientific interest revolved around the fact that the inadvertent precipitation increases had particular bearing upon the general areas of weather modification and air pollution, probably the two greatest current interest areas in meteorology.

Certain meaningful reactions and observations resulted from the presentation of the La Porte results. First, there was the previously mentioned widespread recognition and interest, along with a majority acceptance of the validity of the results. However, some questioning of the findings did arise, a condition not unexpected with the subject of weather modification. These reactions and the subsequent validity controversy (Holzman and Thom, 1970; Changnon, 1970; Ogden, 1969; Changnon, 1971) emphasize the need to evaluate inadvertent modification of the weather in the assessment of environmental problems.

Climatological-statistical investigations similar to that at La Porte are needed for other major urban-industrial complexes to determine whether such dramatic effects exist elsewhere. Therefore, a research program sponsored by the National Science Foundation and Illinois State Water Survey was initiated in 1969 and involved studies comparable to that for La Porte at eight other cities including St. Louis, Chicago, Cleveland, Indianapolis, Washington, D. C., Houston, Tulsa, and New Orleans. These cities were chosen to obtain a variety of different climates, city sizes, basic industrial types, and urban growth rates. Research to date indicates urban-related alterations on precipitation and related conditions at Chicago, St. Louis, Cleveland, and Washington, D. C., but none at Indianapolis (Huff and Changnon, 1970; Huff *et al.*, 1971).

c) Selected examples of urban effects

Selected results from the St. Louis study are illustrated in Figs. 1–6 and Tables 2–3. Essentially, the St. Louis data show an urban-induced increase in warm season rainfall, frequency of rain days and heavy rainstorms, thunderstorm occurrences, and hail-day frequencies. However, little evidence has been found of urban effects on cold season precipitation in the St. Louis area.

Fig. 1 shows the average pattern of summer rainfall (June–August) in the St. Louis area for the 1949–1968 period, expressed in terms of percentage of the urban summer total. That is, the ratio of the average summer rainfall at each station to that at the two central urban stations (rural/urban ratios) was calculated and mapped. In the background, the pie-shaped area extending 25 miles eastward from the city represents the hypothesized area (Major Effect Area) in which an urban effect would most likely occur, based upon climatological considerations of storm motions and durations (Huff and Changnon, 1970). The city area plus those extending NNE and SSE from the city comprise a Minor Effect Area where urban effects would be less pronounced. Two no-effect areas, the Upwind Control Area extending westward from the city and the Downwind Control Area extending eastward from the Major Effect Area, are included for comparative analyses.

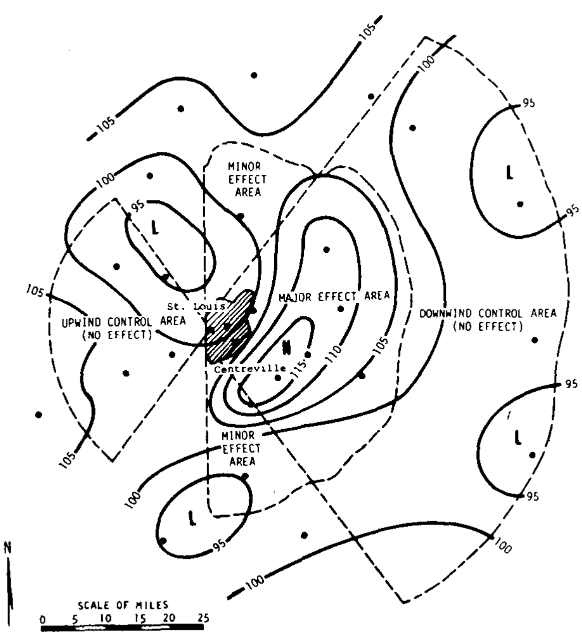

FIG. 1. Average rural/urban ratios of summer rainfall in St. Louis area, 1949–1968.

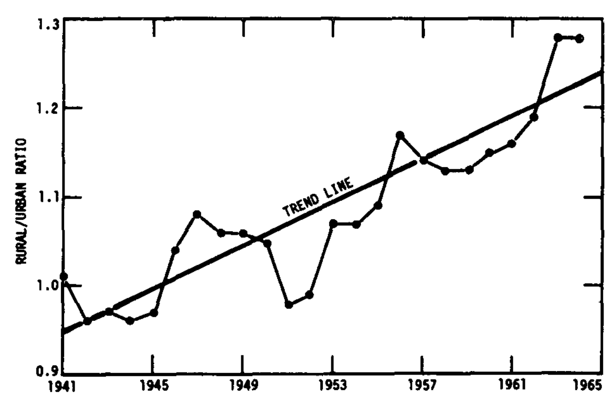

FIG. 2. Five-year moving averages and time trend of Centreville summer rainfall, 1941–1968.

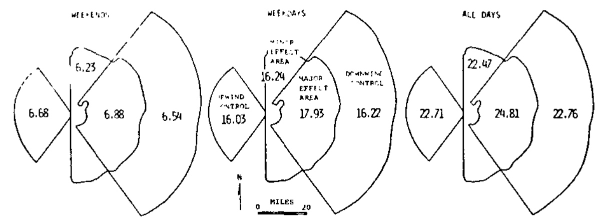

FIG. 3. Average seasonal point rainfall (inches) for April–October period, 1951–1968, in four areas around St. Louis on weekends (Sat.–Sun.) and weekdays (Mon.–Fri.), and on all days.

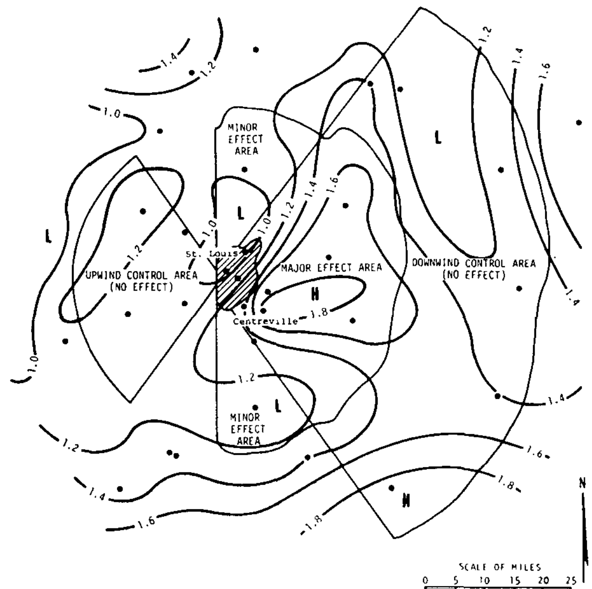

FIG. 4. Rural/urban ratios for number of days with rainfall of 2 inches or more, 1949–1968, in St. Louis.

Of particular interest is the 10–17% increase in summer rainfall that exists in an area 3 to 15 mi downwind of the St. Louis urban-industrial complex (Fig. 1). This downwind high has developed mostly in the past 25 years, as illustrated in Fig. 2 in which the time trend of the rural/urban ratio is shown for 5-year moving averages at Centreville (see Fig. 1) near the center of the high (Huff *et al.*, 1971).

Tables 2–3 summarize the urban effect upon rain-day frequencies and upon weekday-weekend rainfall relations in the St. Louis region. The rain-day increases for the 0.1-inch and higher classes in Table 2 for the Major Effect Area are similar to those found earlier at La Porte (Huff and Changnon, 1970). The warm season increases were most notable when rain days were measured at the 0.25-inch level and higher, indicating that the St. Louis urban effect(s) is largely one of rain enhancement in existing rain systems and particularly in the stronger convection systems. This conclusion is supported further by the fact that significant increases in heavy rainfall occurrences, thunderstorm days, and hail days were found also (see Figs. 4, 5, 6). Additional

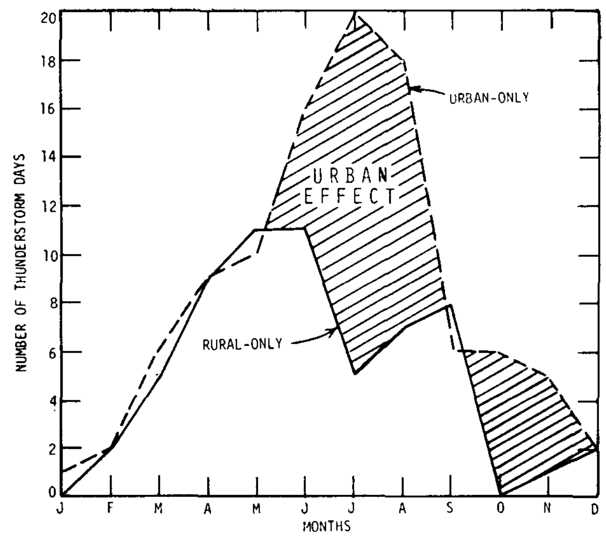

FIG. 5. Frequencies of thunder days when isolated thunderstorms(s) occurred only over the St. Louis urban area and only over the upwind control (rural) area during 1950–1958.

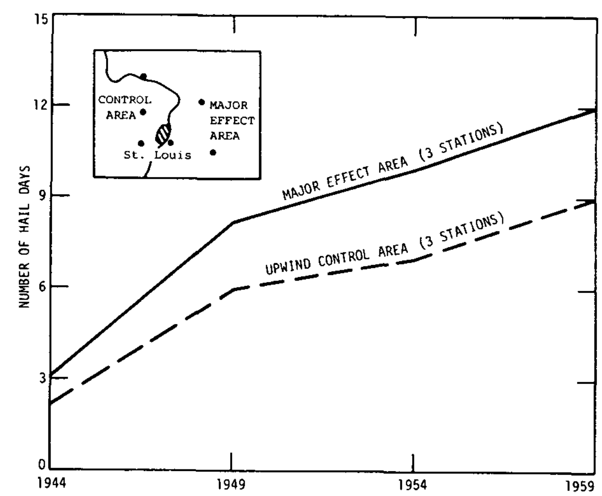

FIG. 6. Frequency of summer hail days in St. Louis area.

evidence of an urban effect and likely association with human activity is provided by Table 3 and Fig. 3. The greater frequency of rain days in the Major Effect Area during the warm season compared with the two control areas is shown in Table 3 and again indicates rain enhancement is most pronounced at the heavier intensities. Fig. 3 shows greater amounts of rainfall in the Major Effect Area in all cases, but the percentage difference is greatest on weekdays. These weekdays-weekend differences in rain-day frequencies and rain quantity are major findings that establish man-made effects on rainfall and in proving that the downwind rainfall high (Fig. 1) is not produced by any local orographic effects.

Figs. 4, 5 and 6 illustrate urban effects on severe weather events in the St. Louis region (Huff *et al.*, 1971).

TABLE 2. Point rain-day frequencies in St. Louis area, 1951–1968.

	Warm season (Apr.–Oct.)				Cold season (Nov.–Mar.)			
	UC[1]	ME[1]	MJE[1]	DC[1]	UC	ME	MJE	DC
Number days ≥0.01″	1030	1060	1035	966	472	509	478	456
Number days ≥0.10″	731	716	730	713	415	403	437	434
Number days ≥0.25″	469	492	506	480	252	246	271	262
Number days ≥0.50″	272	277	294	272	124	119	145	144

[1] UC = Upwind Control Region; ME = Minor Effect Region; MJE = Major Effect Region; DC = Downwind Control. Point average values based on 4 stations in each area.

The ratio map of Fig. 4 shows that the frequency of heavy rainstorms (days with 2 inches or more) is significantly greater in the Major Effect Area where 80% more occur, on the average, than in the city. Fig. 5, showing a comparison between frequency of isolated thunderstorms occurring only in the urban area and those only in the upwind control (rural) area, indicates the urban environment is instrumental in the development of summer thunderstorms (Changnon, 1969). Fig. 6 compares summer hail-day occurrences between the Major Effect Area and the Upwind Control Area (based on 3 stations in each area). Downwind enhancement of hail occurrence is quite apparent.

3. METROMEX

The La Porte climatological study and ensuing questions revealed that atmospheric measurements of precipitation processes in urban areas were needed to evaluate, substantiate, and describe the potential causes of urban-induced precipitation. Explanations that were offered for these increases included: 1) urban-related increases in active condensation nuclei and ice nuclei, both important in the cloud and raindrop formation, 2) roughness from the city resulting in low-level turbulence and increased upward vertical velocities, 3) urban heating (due to greater radiation and combustion processes) which would also lead to upward motions of the air to initiate or enhance convection, and 4) additional moisture from industrial processes such as cooling towers.

Inasmuch as a precipitation process (and alteration thereof) represents a rather complicated system involving a series of motions and the transfer of energy in the atmosphere, only definitive field studies involving a complex set of measurements, both at the surface and in the low-to-middle atmosphere, can furnish the information needed to establish the connection between urban effects and precipitation increases, and to ascertain the cause or causes for these increases. Thus, any substantial increase in knowledge about urban-weather effects required two things: 1) much more complete climatological data, and 2) physical measurements and tracer experiments in and around clouds affected by the urban-industrial complex. Therefore, an urban-weather research program focusing on a field project adequate to make the necessary measurements was planned and organized by the Illinois State Water Survey and three other atmospheric science groups. The site chosen for the field project was the St. Louis area where the urban climatic study had identified the existence of an urban effect on precipitation.

TABLE 3. Percentage increases in weekday values of daily rainfall in Major Effect Area at St. Louis.

Daily rainfall (inches)	Increase, per cent	
	Major vs. upwind	Major vs. downwind
≥0.01	3	9
≥0.10	1	4
≥0.25	23	17
≥0.50	11	11

a) Plans, organization, and management

Scientists from the Argonne National Laboratory, University of Chicago, and the University of Wyoming began discussions with scientists from the Illinois State Water Survey during the summer of 1969 to develop specific scientific plans for an urban-rain research program. Consideration of the available climatological results, available resources, and the locations of the four research groups resulted in the choice of the St. Louis area as the site of the field project, the major effort of the program. Through a series of meetings which ended in March 1970, a comprehensive project plan was evolved. This plan identified all measurements considered essential to the study of urban effects on precipitation.

The investigative conglomerate is reasonably unique in that it includes groups from a state university, a state research institution, a private university, and a national laboratory, all acting cooperatively to establish their own measurement and study areas within the total plan. These study areas coupled together provide for the essential measurements established in the plan.

A flow diagram of METROMEX and the field project at St. Louis is shown in Fig. 7. The climatological studies at St. Louis were able to answer the first question in the flow diagram with a "yes," allowing the program to proceed in relation to the field project. Awareness of potential interactions for various studies in the social and physical sciences with METROMEX is

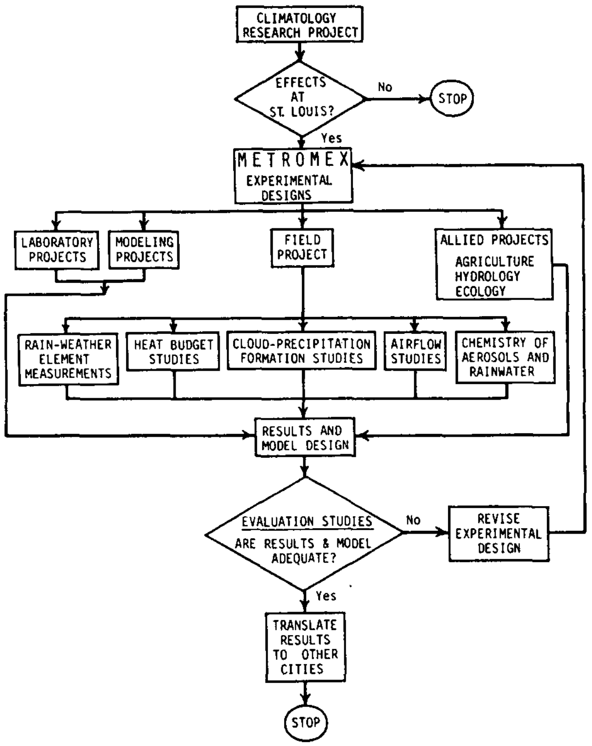

FIG. 7. Outline of METROMEX, a program to investigate modification of weather precipitation processes by urban effects.

noted by the inclusion of allied interdisciplinary research in the planned program. (Research in related physical sciences and based on METROMEX data has already begun at St. Louis.) Importantly, the four research groups also recognized the need to provide results from the field project that would be translatable to other cities through modeling research that would be concurrent within METROMEX.

Climatological research results indicated that a 5-yr study period would be necessary to collect data adequate to define the phenomena, and the plan optimistically called for the initiation of the METROMEX field project in 1971. The primary operational period in summer was dictated also by the climatological results which showed the rain increases to be most pronounced during summer.

The final planning of METROMEX with regard to management and funding was unique in that each group would secure its funding from whatever private, state, or federal sources that wished to furnish support. This meant that each group had to have one or more research projects that were viable scientific experiments even if all other projects failed to be funded or accomplished. However, the conglomerate believed that the research results would be more than the sum of the parts because of the synergism of the combined projects.

Each of the four groups identified specific portions of the five main measurement areas of the field project

TABLE 4. Research areas of METROMEX and groups involved in each area.

Research area	Participating groups*
Assessment of weather elements	
Ground networks	ISWS
Radar	ISWS, UC
Statistical data analysis-evaluation	ISWS, UC
Chemistry of aerosols and rainwater	
Aerosols	ANL, ISWS
Rainwater	ISWS, ANL
Cloud and precipitation formation	
Nuclei measurement	UC, UW, ISWS
Cloud structure	UC, UW
Precipitation characteristics	UC, UW
Atmospheric electricity	ISWS, UC
Heat budget	
Radiometric mapping	UC
Thermal structure	ISWS, UC, UW
Modeling of airflow and cloud development	
Airflow measurements	ANL, UW
Modeling	ISWS, UW, ANL

* ISWS = Illinois State Water Survey; UC = University of Chicago; ANL = Argonne National Laboratory (AEC); UW = University of Wyoming.

shown on Fig. 7. The research desires and areas of responsibility selected by each group in March 1970 are shown in Table 4. Each group proceeded to develop its own detailed research plans and proposals, and preliminary site investigations were begun. Since the summer of 1971 was chosen for initiation of the St. Louis field project, each group had approximately one year to prepare plans, secure funding, and install equipment. An outline of the facilities, types of equipment, and measurements employed in METROMEX 1971 is presented in Fig. 8.

Another facet of the 4-group plan was that the program was to be "open-ended" in that other research groups who wish to become involved in either the atmo-

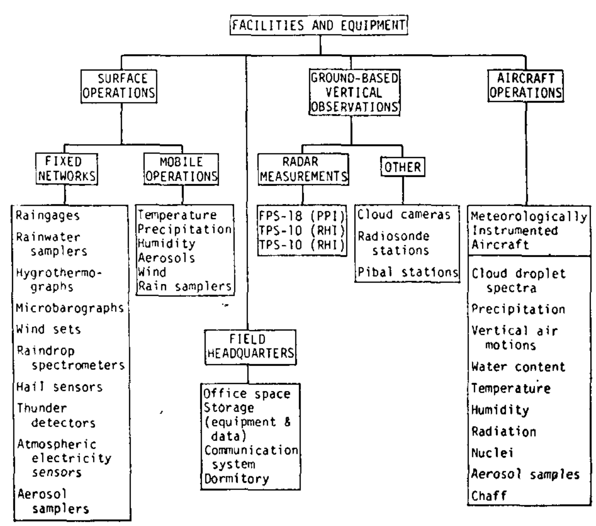

FIG. 8. Facilities and equipment outline for the 1971 METROMEX field project.

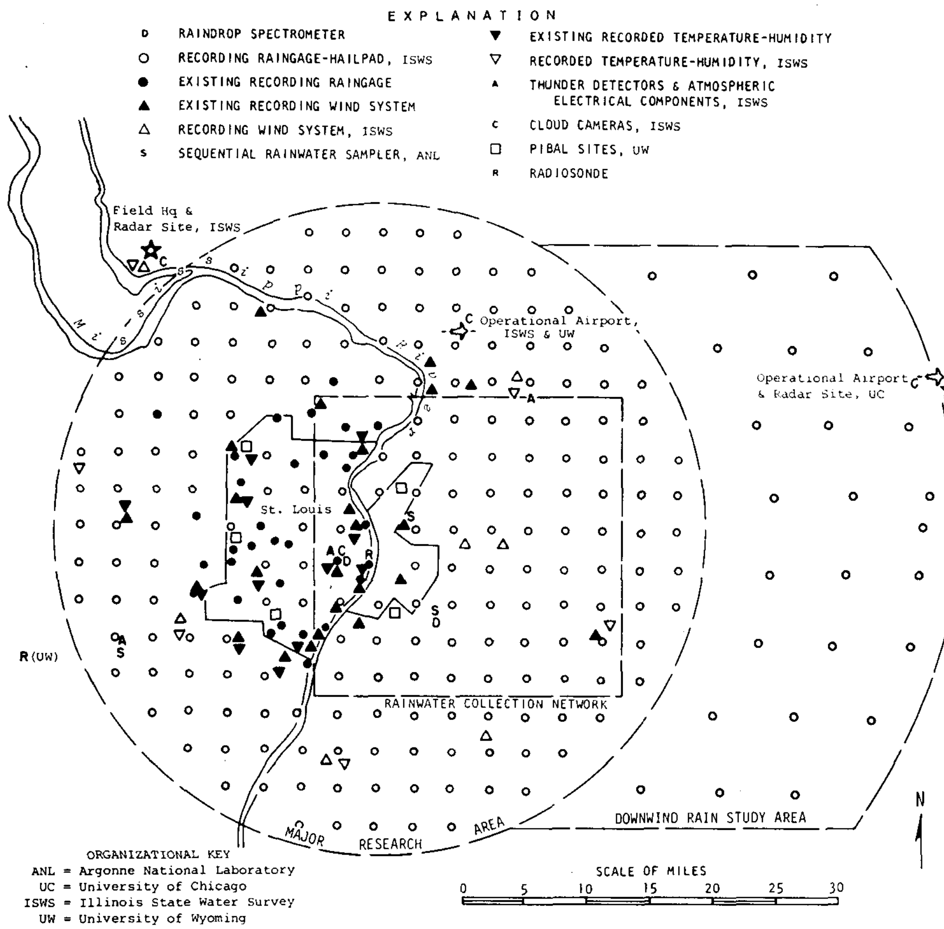

FIG. 9. METROMEX field study area with existing and installed instruments and facility sites.

spheric sciences phases or in the allied projects (which would benefit from or utilize the project's weather data) are welcome and can be involved along the same lines of independent effort and funding. In fact, research groups from the Battelle Pacific Northwest Laboratories, the Stanford Research Institute, and the University of California at San Diego, each brought equipment and staff to St. Louis during August 1971. Their projects were established at St. Louis to take advantage of the data emanating from the existing METROMEX field projects. It is our understanding that other major projects for the St. Louis area are being planned by the Environmental Protection Agency, the National Center for Atmospheric Research, and the National Oceanic and Atmospheric Administration. These projects will deal with air pollution, atmospheric chemistry, forecasting, and mesometeorology.

Continuity in planning and operations of METROMEX is handled by the principal investigators and scientists from each group who are organized into a project panel called the Group Atmospheric Sciences Panel. A Program Coordinator, elected each year by this panel (S. A. Changnon, Jr., was elected in 1971), acts as a focal point for program communications, both scientific and public, and for data exchange.

The fact that four groups have been funded and METROMEX has begun indicates a willingness on the part of various federal agencies to support a relevant scientific program that does not have strong centralized control. The program is a version of "big science" in reverse with all of those involved being there entirely by their own institutional interest for scientific research, and hence may achieve an interest and responsibility level that has been lacking in some large scientific projects under the centralized control of a single agency or organization. In the final analysis, whether a program structured like METROMEX is successful will depend on the scientists involved and their willingness to cooperate, to exchange data, and to produce results in a reasonable time.

b) Specific group plans and measurement projects for 1971–1972

In the past 18 months, the four groups that planned METROMEX have each evolved rather detailed project plans. Each secured funding adequate to operate and collect measurements in the summer of 1971 and to analyze the resulting data. Certain groups are also funded for the 1972 operational-analytical phase.

1) Argonne National Laboratory. The Argonne effort is twofold: 1) a study of precipitation scavenging under the direction of D. F. Gatz, and 2) an investigation of the effect of an urban complex on the winds in the boundary layer, under the direction of B. Ackerman. Their work is sponsored by the Atomic Energy Commission.

The precipitation scavenging studies are an effort to understand more fully the processes by which airborne particles enter precipitation processes. If urban pollutants modify rainfall, the scavenging processes are clearly important to the overall explanation of the phenomenon. Samples of airborne particulate matter and rain were collected both in and upwind of the region of urban influence. The ground-level measurements included: 1) concentrations of 10–20 elements that are components of atmospheric particles, collected on filters at three locations; 2) size distributions for the same elements, using three filter-backed 8-stage cascade impactors; and 3) concentrations of the elements in rain, using three sequential samplers (Fig. 9), each able to collect 70 samples from 2 inches of rain. In addition, concentrations were measured aloft in the urban mixing layer, using filter samples collected by aircraft.

The rain samples are being filtered to separate soluble and insoluble fractions. The rain-soluble, rain-insoluble, filter and impactor samples are being analyzed for cadmium, calcium, copper, iron, lead, magnesium, manganese, nickel, potassium, sodium, zinc, and other elements using both atomic absorption and neutron activation techniques. A large number of samples are first being analyzed for a few elements by atomic absorption spectrophotometry. On the basis of this screening, about 3–5 cases per summer will be selected for detailed chemical and meteorological analyses. Field sampling was done from June to August 1971.

The airflow study is concerned with both the mean and turbulent components of the wind field. The studies of the mean flow will seek to determine 1) if and when a city circulation exists, 2) the character and magnitude of urban-induced modifications of the wind profile and of the mean wind field and its derivatives, and 3) the height to which the effect of the city extends. The key measurements were provided by simultaneous pilot balloon releases, at 20- to 30-min intervals, from ten double theodolite sites, during six weeks in the summer of 1971. The array of balloon release points varied, depending on larger scale meteorological conditions. The measurements are being computer-processed to yield wind speed and direction and balloon location at specified levels in the planetary boundary layer.

The goal of the studies dealing with the turbulent part of the wind field is to establish whether there are detectable urban-rural differences in turbulence characteristics at heights greater than 200 or 300 m above the surface. Aircraft measurements were made during a 2-week period in August 1971. Flight paths provided either horizontal mappings or vertical cross sections. In both cases, data were obtained directly over the city and over the upwind and downwind rural areas.

The Air Weather Service provided the equipment and personnel for the pilot balloon observations, and the National Center for Atmospheric Research provided the airplane support.

2) University of Chicago-Cloud Physics Laboratory. This group, under the direction of R. R. Braham, Jr., has three major goals: 1) to determine how natural clouds and their precipitation mechanisms are modified by the ingestion of urban pollutants; 2) to study modification of precipitation using radar-oriented measurements; and 3) to explore the solar and terrestrial radiation budgets of the urban complex. Many of the measurements for goals 1 and 3 were collected with instruments aboard a Lockheed Lodestar. A ground based 3-cm RHI radar system located to the east of the research area (Fig. 9) was employed to satisfy goal 2. The operational period was July–August of 1971, and future periods will include February 1972 and July–August 1972. This research work is being sponsored by the National Science Foundation.

The flight-oriented part of the University of Chicago effort stressed cross sections at 1500–5500 ft MSL upwind versus downwind of the city, and sampling of large numbers of clouds near cloud-base levels. Airborne measurements were taken to get cloud particle spectra, cloud water content, precipitation particle spectra, cloud condensation nuclei, ice nuclei, standard weather conditions, and electrical conductivity.

The precipitation measurements utilizing the RHI radar concern the study of cloud microstructure and will be used to extend the "line" airplane samples. Precipitation measured by radar is being studied as to its frequency, location, height, and intensity.

The exploratory studies in solar and terrestrial radiation budgets primarily concern the heat budget and heat island of the city. Airborne measurements of radiation and solar flux were made during selected synoptic situations to develop the vertical-horizontal temperature structure.

3) Illinois State Water Survey. As with the other groups, the Water Survey's plans and interests in METROMEX evolved from past principal research areas and available instrumentation. The principal investigators are S. A. Changnon, Jr., and R. G. Semonin. The Water Survey's historical interest in precipitation studies, climatology, instrumentation, and cloud physics led to three major goals.

The major METROMEX goals of the Survey include: 1) the study of severe local weather phenomena (heavy rainstorms, thunderstorms, and hailstorms) in summer so as to describe the temporal-spatial relationships of these events in the St. Louis urban area with special reference to their relationships under varying synoptic weather conditions; 2) the study of rainfall and radar data to assess the magnitude and location of the urban-related precipitation changes with specific reference to time-space analyses of rainfall and synoptic weather analyses; and 3) an atmospheric tracer project involving placement of a unique chemical tracer into convective storms, and subsequent analysis to determine the temporal and spatial distribution of the tracer at the surface following its interaction with the precipitation process. Thus, the Water Survey's principal overall interest is to study, understand, and evaluate the urban-induced rainfall increases with respect to the water resources (both quality and quantity) of Illinois.

Knowledge of the magnitude and causes of such inadvertent changes at St. Louis will be useful in preparing for planned rain enhancement efforts in Illinois, in forecasting of urban rainfall and other weather conditions, and in assessing the benefits and disbenefits to activities directly affected, such as urban planning and agricultural production downwind of the city. For example, the primary ground-water supply area for the industrial-urban complex in Illinois east of St. Louis is located where the rainfall increases have occurred, and this ground-water area depends heavily upon rainfall recharge.

To obtain the measurements necessary to fulfill the three goals of the Water Survey requires several instrumental and observational tasks. These tasks include the installation and operation of 1) a large dense network consisting of 220 recording raingages and hailpads distributed evenly throughout the major research area of 2200 mi^2 (Fig. 9); 2) two radar systems located northwest of the major research area (Fig. 9); 3) "key stations" of various instruments including those that measure and record thunder, four atmospheric electricity components, clouds (time-lapse photography), raindrop size spectra (spectrometers), temperature, humidity, and wind; and 4) a series of surface stations that record temperature, humidity, and winds.

Other tasks include the release of rare tracer materials both at the surface and by an aircraft into storm updrafts and measurement of these in a sub-network of 75 rainwater collectors (outlined on Fig. 9) and aircraft measurements of low-level temperature, humidity, and aerosols throughout the urban-rural areas. Also involved has been the development and operation of a Field Headquarters for the entire project (Fig. 8).

Funding has been received from the State of Illinois, Atomic Energy Commission, and National Science Foundation. The indicated measurements were made throughout the summer of 1971, although the aircraft operations were conducted from mid-July through August. Data resulting from the Water Survey's measurement program METROMEX 1971 are being digitized onto punched cards and/or magnetic tape for analysis.

4) University of Wyoming. The Wyoming research group under the leadership of A. H. Auer, Jr., and D. L. Veal has three principal objectives. The first concerns study of the mesoscale circulation features with observations to determine the kinematics of the urban atmosphere so as to derive input to numerical models not unlike the Lavoie (1968) model. The second principal objective concerns study of nuclei concentrations to establish the production of cloud, Aitken, and ice nuclei by the urban environment. The third objective concerns study of cloud and precipitation processes (urban vs. rural), specifically: 1) the transfer process of the urban aerosols to cloud particles, 2) the effects of urban-produced cloud nuclei on cloud structure, 3) the coalescence mechanisms of precipitation associated with pollution, 4) the role of urban-derived ice nuclei, and 5) evolution of the resulting cloud particles into precipitation.

METROMEX 1971 operations and equipment to provide data for the mesoscale circulation studies (goal 1) included the installation and operation of the radiosonde unit west of St. Louis (Fig. 9) to make ascents to coincide with the NWS radiosonde station in central St. Louis as well as frequent serial ascents. Two mobile meteorological vehicles made surface temperature, wind, and humidity measurements, and 4 pibal stations arrayed in the urban perimeter (Fig. 9) provided added windflow data. Aircraft data and radar-chaff measurements from 1971 will help describe the 3-dimensional fields of wind, humidity, and temperature.

The second goal involving measurement of various nuclei is based upon aircraft measurements of cloud nuclei, Aitken nuclei, ice nuclei, and freezing nuclei in cloud water from the urban and rural environment. Rainwater samples were collected with portable samplers distributed by vehicles, and freezing nuclei content will be determined from these rain samples.

The third goal involves airborne measurements of the size distributions of aerosols, cloud droplets, and hydrometeors. These were measured at various heights in clouds over the upwind rural area and urban area.

The Wyoming 1971 field operations occurred during August. The Beechcraft C-45H meteorological aircraft was based at the Alton Airport (Fig. 9), and radar-direction of aircraft operations was accomplished at the Field Headquarters. The University of Wyoming research effort is being sponsored by the Department of Health, Education, and Welfare.

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news and notes

Former BULLETIN editor retires from AWS

Robert G. Stone, editor of the BULLETIN OF THE AMERICAN METEOROLOGICAL SOCIETY from 1935 to 1955, retired from his position as Chief of Technical Files for Aerospace Services, Headquarters Air Weather Service, on 31 May 1971, after nearly 28 years of service. His interests in meteorology extended from observing to forecasting and research, and from publications to teaching. In 1956 he was awarded the Charles Franklin Brooks Award for Outstanding Services to the Society (then known as the Award for Outstanding Services to the Society) for "his many years of faithful editorship of the BULLETIN OF THE AMERICAN METEOROLOGICAL SOCIETY and his active participation in committee and council work."

Stone began his meteorological career in 1933 when he became assistant observer at the Mount Washington Observatory in New Hampshire, and was promoted to observer the next year. During his tenure at the observatory he recorded two rare atmospheric phenomena. The first of these was an unusual halo of 24°30′ radius recorded during the fall of 1933, and the second occurred during the great storm of 11–12 April 1934, when the observatory's anemometers recorded wind speeds of 231 mph—a world record at the time.

In 1935 he began working at the Blue Hill Observatory in Milton, Mass., where he was research assistant under the late Charles Franklin Brooks (see BULLETIN, **51**, 608–610). During this time he was assistant secretary of the AMS, served on the International Union of Geodesy and Geophysics Committee on Snow and Ice, edited the Biometeorological Section of Bibliographical Abstracts, and compiled an exhaustive bibliography for synoptic meteorologists which was later incorporated into Jerome Namias' book *Air Mass and Isentropic Analysis*. Stone left Blue Hill in 1939 to join the School of Tropical Medicine in Puerto Rico. Some of his experiences there were later included in his book *The Climate of the Virgin Islands*. In 1940 he went to New York University as a research associate.

Col. Douglas C. Purdy, Chief of Staff, Hq. Air Weather Service, presents Mr. Robert G. Stone with a certificate of service honoring his retirement as Chief of Technical Files for Aerospace Services, for almost 28 years of service. (USAF Photo).

By 1944 Stone was research assistant in the Research Section of the Weather Division of the Army Air Force under the late Dr. Harry Wexler. He transferred from there to the Scientific Services Section of the Air Weather Service in 1948, where he remained until his retirement, overseeing the editing and publication of technical documents and the management of the Headquarters Air Weather Service Library.

(More **news and notes** on page 1023)