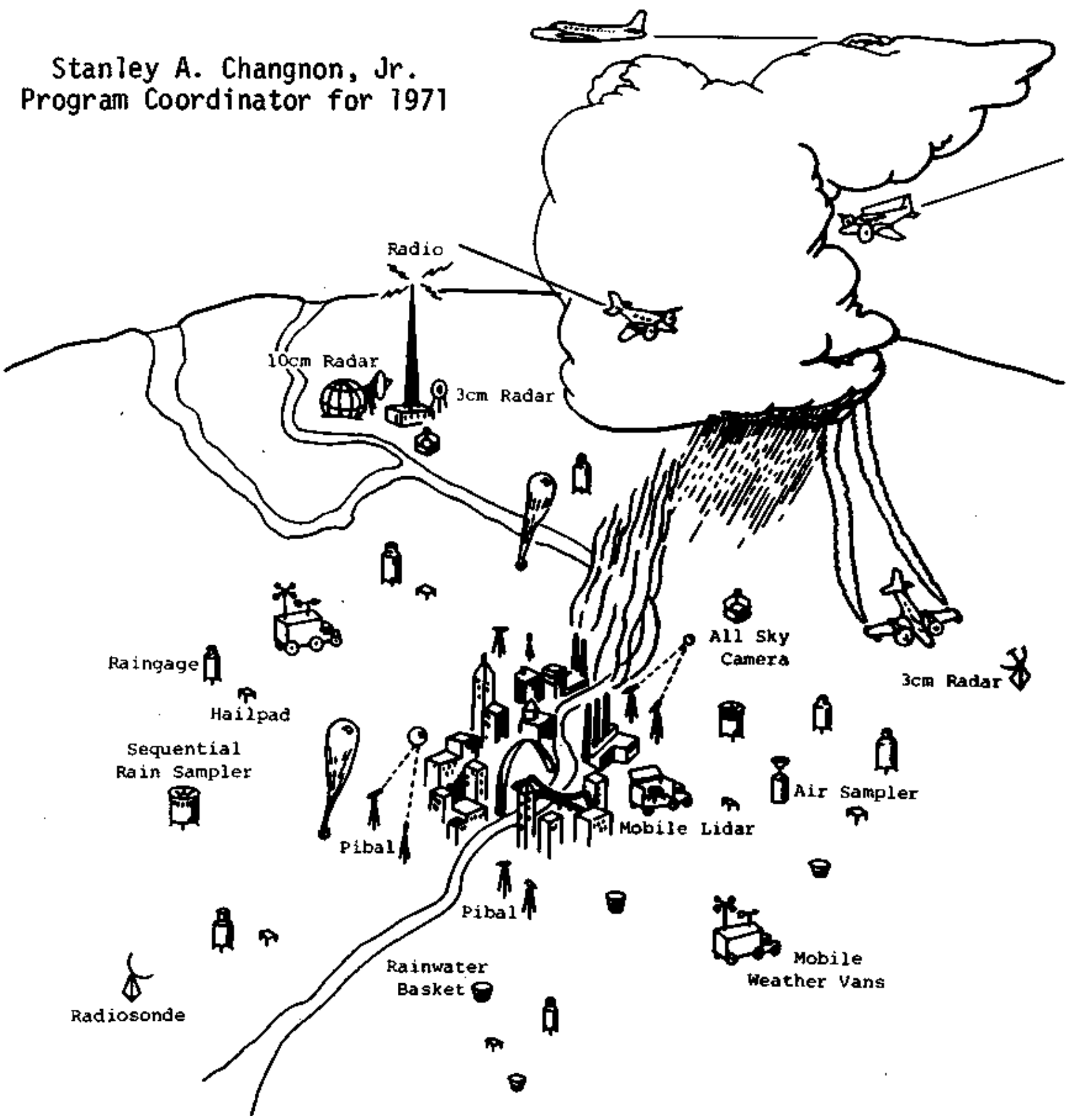
# 1971 OPERATIONAL REPORT
## FOR
# METROMEX

Stanley A. Changnon, Jr.
Program Coordinator for 1971




A Joint Program involving groups from Argonne National Laboratory, University of Chicago, Illinois State Water Survey, and University of Wyoming

November 30, 1971
Box 232, Urbana, Illinois 61801

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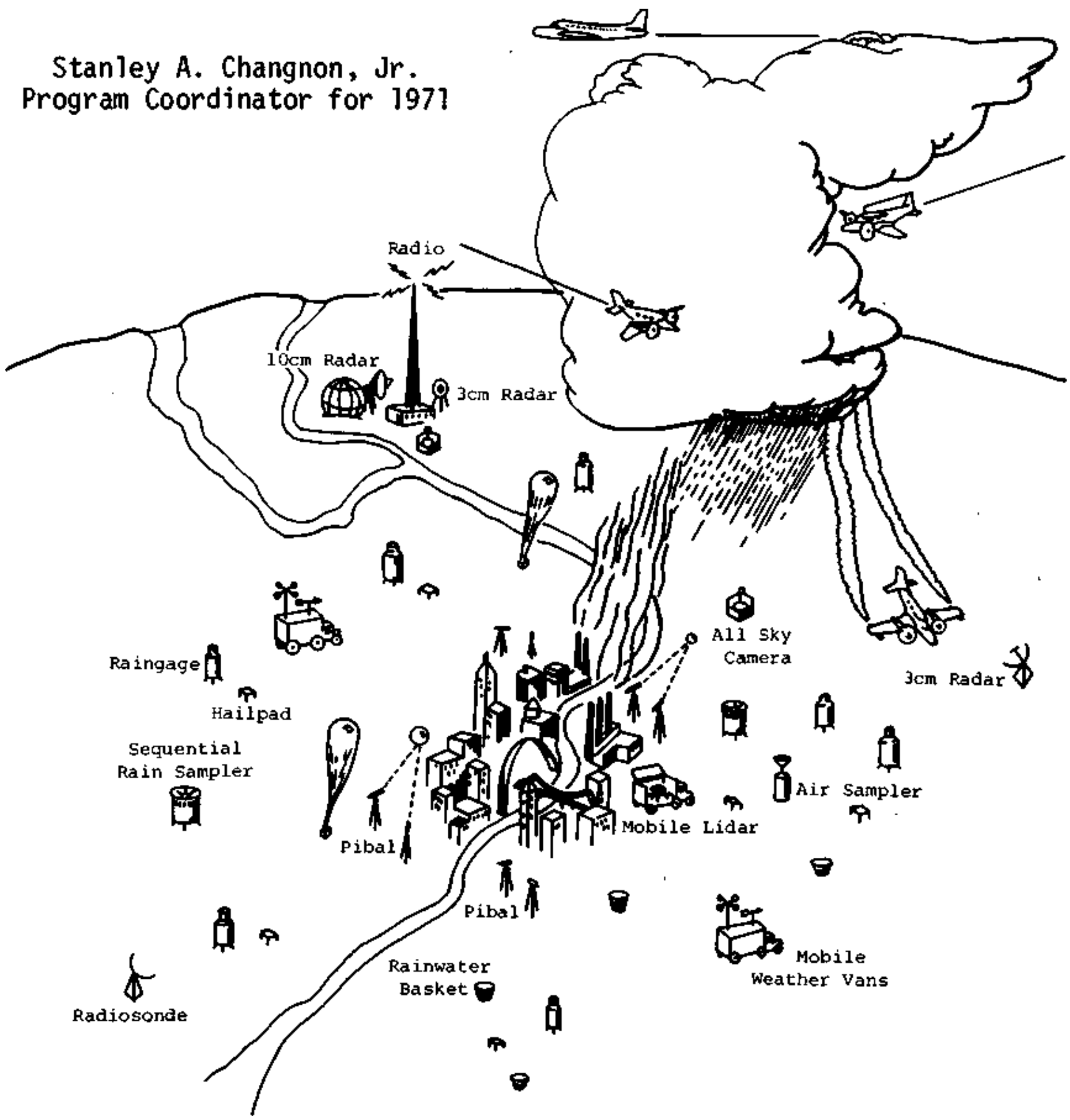


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# INTRODUCTION

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 the urban-industrial complex at St. Louis. 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 Meteoro-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 June-August 1971.

## Goals

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 report is to describe briefly the basis for METROMEX, the organizational aspects of the program, and the 1971 activities of the research groups involved in METROMEX. The organizational aspects of the program described include the research plans, the physical organization, and the program management. In the final section of the report, the goals, 1971 field measurements, and selected

1971 results from each participating group are presented.

## Background

The LaPorte precipitation anomaly and ensuing research 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 their increases. Thus, any substantial increase in knowledge about urban-weather effects required two things: 1) much more complete climatological type 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 four aforementioned atmospheric science groups. The site to be chosen for the field project was largely dependent upon results from an extensive urban climatic study of the Water Survey.

# PLANS, ORGANIZATION, AND MANAGEMENT

## Plans

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 climatological results, available resources, and the juxtaposition 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 program plan was evolved. This plan identified all measurements considered essential to the study of urban effects on precipitation.

The original investigative conglomerate was reasonably unique in that it included 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 program plan. These study areas coupled together provide for the essential measurements established in the plan.

A flow diagram of METROMEX and the field project is shown in Fig. 1. 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 a field project at St. Louis. Awareness of potential interactions for various studies in the social and physical sciences with METROMEX is noted by the inclusion of allied interdisciplinary research in the planned program. 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.

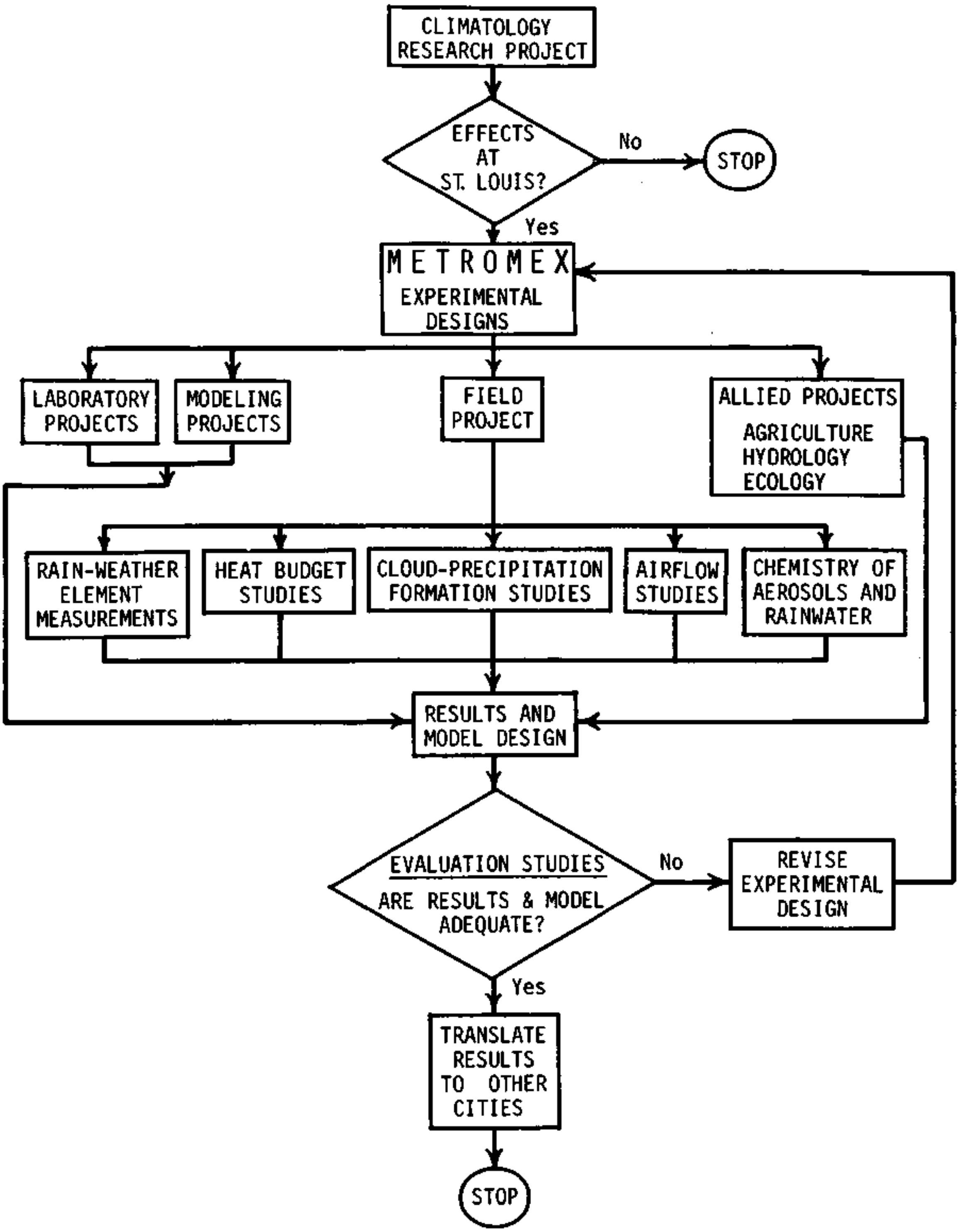



Figure 1. Plan Diagram for Metromex

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

Organization

Each of the four groups identified specific portions of the five main measurement areas of the field project shown on Fig. 1. The research desires and areas of responsibility selected by each group in March 1970 are shown in Table 1. 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 its plans, secure funding, and install equipment. An outline of the facilities, types of equipment, and measurements employed in METROMEX 1971 is presented in Fig. 2.

Another facet of the 4-group plan was that the program was to be "open-ended" in that other research groups who wished to become involved in either the atmospheric sciences phases or in the allied projects (which would benefit from or utilize the project's weather data) were welcome and could 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,

Table 1. 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 |
| 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; ANL Argonne National Laboratory (AEC)
UC - University of Chicago; UW University of Wyoming

and the National Oceanic and Atmospheric Administration. These projects will deal with air pollution, atmospheric chemistry, forecasting, and mesometeorology.

Management

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 (Mr. 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 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 various projects.

## SUMMARY OF 1971 OPERATIONS

The 1 groups that planned METROMEX each participated in the field project, METROMEX 1971, during all or portions of the June-August period. Three other research groups brought equipment and personnel to St. Louis during this period to conduct experiments that benefited from the operational facilities, equipment, and data resulting from the METROMEX activities. The distribution of most METROMEX equipment and facilities installed and operated in 1971 is shown in Fig. 2.

The operational periods for the major study areas of each of these 7 groups is shown in Table 2. Inspection of this table reveals that all groups focused on operations in August. The Water Survey's rain and severe weather studies began first, with their surface networks operations in the first week of June.

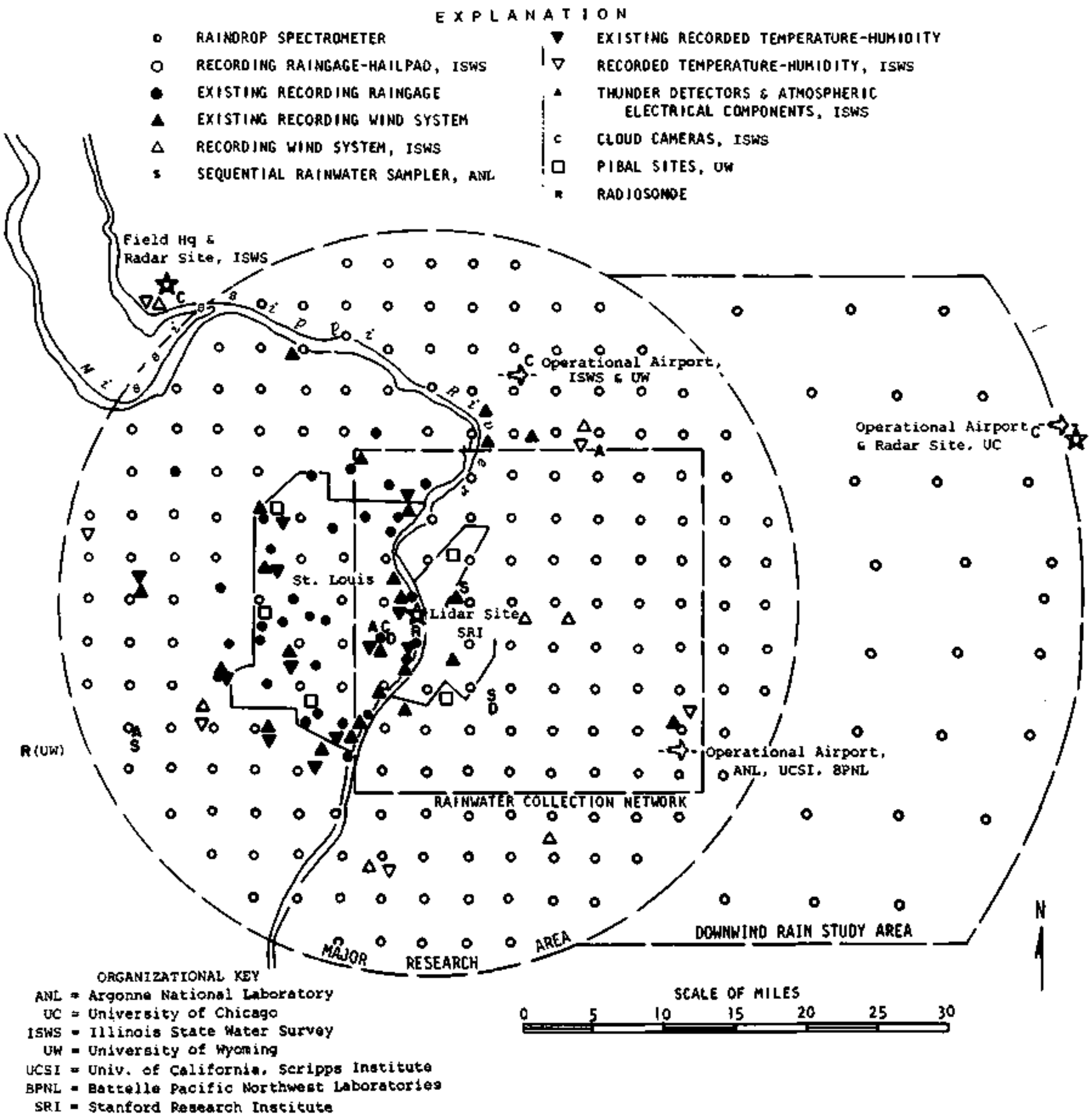
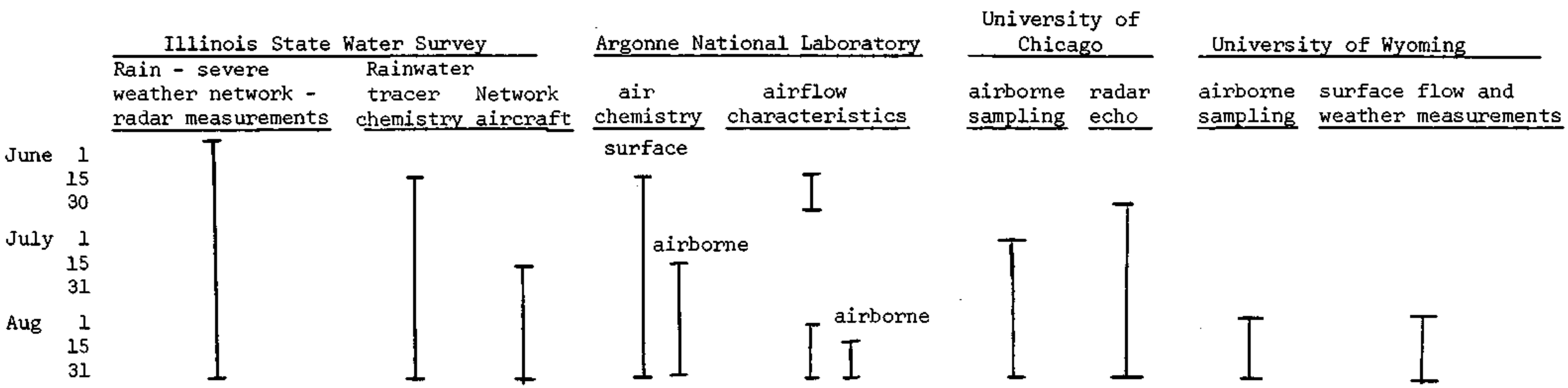


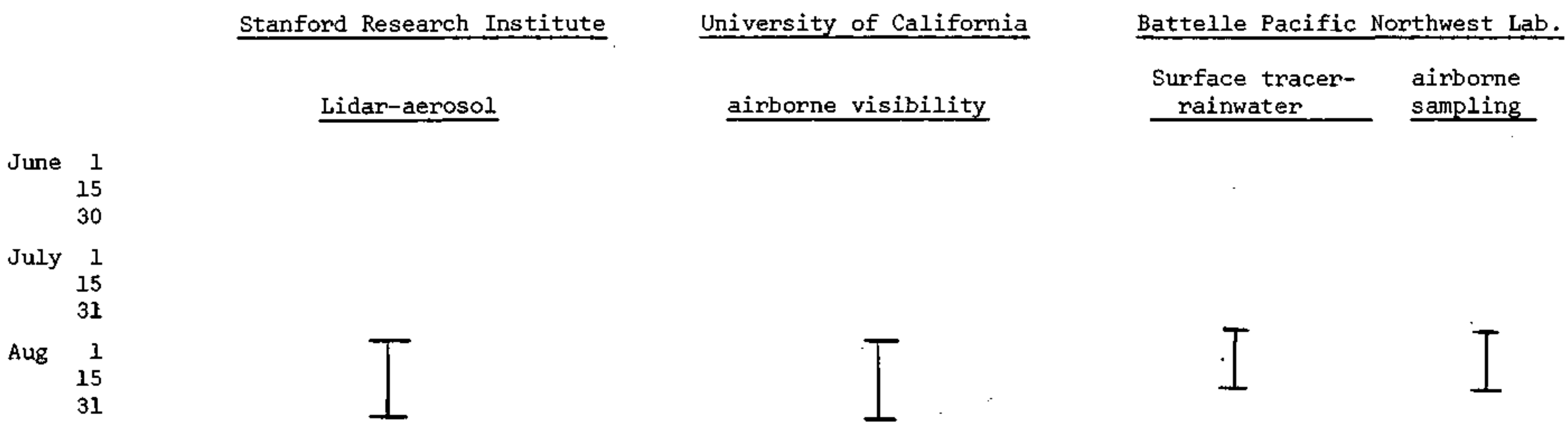

Figure 2. Metromex Installations in 1971

Table 2. METROMEX Operations in 1971 .

METROMEX Groups




Allied Groups



## Coordination and Cooperation

Coordinated operations between groups was self-organized as desired. A project meeting involving the principal scientists for all 7 groups was held in Alton, Illinois, on August 16. The missions of each group were discussed, and a day of joint, extended data collection was chosen (1200 on August 23 to 1200 on August 24).

It should be realized that the coordination of most operations was not a major problem because the various research goals led to operations that were either continuous or oriented to specific weather and/or time periods. For instance, the principal radar system of the Water Survey plus all of the surface network equipment of the Water Survey were operated on a 24—hour, 7-day a week basis. Furthermore, the specific and largely different aircraft missions did not necessitate direction nor close coordination of the aircraft operations. For example, the Water Survey aircraft operations were primarily aimed at injection of tracer material into convective clouds in certain restricted areas. Conversely, Wyoming aircraft operations were oriented to collection of airflow data for modeling studies at very low levels in discrete morning periods and to individual detailed cloud studies (penetrations) upwind and downwind of the city. The Chicago aircraft operations consisted of cloud and atmosphere sampling on a semi-routine basis at pre-determined heights and with fixed flight patterns over and around St. Louis. Thus, almost all field operations did not require an integration of operations to be effective.

## Several Examples of Cooperation Between the Research Groups

The facilities at the Water Survey's radar site at Pere Marquette State Park (Fig. 3) housed, in addition to two radars, the base radios of the communication systems of the Water Survey and of the Wyoming group. It also served as the weather analysis-forecasting center for the Water Survey, Battelle, Chicago, and Wyoming projects. This site served also as the project operations-information center for the various daily operations of each group.

The Water Survey serviced an Argonne 24-hr air sampler from 2 July to 30 August, and also serviced 3 other samplers once a week for 5 weeks during this period. The Water Survey also furnished a facility to Wyoming for installation of a radio and access to radar scopes for limited direction of their aircraft. In addition, the Water Survey supplied rainwater samples to Battelle, and assisted Argonne in finding equipment sites.

The Argonne group provided test samples of air filters and rainwater to the Battelle group. These two groups coordinated air filter sampling flights for added areal coverage. The Argonne group is also supplying the Water Survey with water samples from the sequential rain samplers.

Staff

Table 3. Staff Efforts in Field During 1971.

| | Man-Months in field, June-August | |
|---|---|---|
| Groups | Professionals | Students and allied personnel |
| Argonne | 6 | 45 |
| Chicago | 7 | 10 |
| Illinois | 31 | 42 |
| Stanford | 9 | 0 |
| Wyoming | 9 | 27 |
| Totals | 62 | 124 |

Major Facilities and Equipment

The major operational equipment installed by Metromex participants and used in the June-August 1971 operational season is enumerated below.

Radars

TPS-10 RHI (3-cm)
FPS-18 PPI (10-cm)
TPS-10 RHI (3-cm)
Mark VIII Lidar (0.69 μm)

Surface Weather Instruments

228 recording raingages
228 hailpads
7 weather recording stations
6 recording wind stations
3 time lapse cloud cameras
3 thunder detectors-recorders
2 atmospheric electricity stations
2 raindrop spectrometers
1 radiosonde station
13 Pibal staitons (double theodolite)
3 Andersen samplers
2 sequential rainwater samplers
1 nephelometer
4 filter samplers
1 thermosonde

Mobile Facilities

2 meteorological vans
4 rainwater collection vehicles

Aircraft Facilities

1. C-45 (UW) 4-27 August
2. Queenaire (ANL) 18-28 August
3. Lodestar (UC) 12 July-31 August
4. Piper Navajo (ISWS) 18 July-28 August
5. RB-57C (ANL) 16 July-26 August (only 7 separate days in this period)
6. C-130 (UCSI) 11-24 August
7. RB-57F (BNWL) 3-18 August

# REPORTS OF PARTICIPATING GROUPS

# ARGONNE AIRFLOW STUDIES IN METROMEX-1971[1]

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## 1. Introduction

The structure of the planetary boundary layer is profoundly influenced by the characteristics of the underlying surface. Thus when passing over a city, with its distinctive land usage and effluents, the lower atmosphere may be expected to soon exhibit features systematically different from those which characterize the air over nearby rural areas. Modification of the air flow is of particular concern since the local winds determine the rate and direction of the transport and turbulent dispersion of gases, particles and heat. Alteration can come about as a result of both mechanical effects due to the change in roughness and dynamic effects arising from differences in the thermal properties of typical urban and rural surfaces.

Few studies have been made of the winds in and around an urban complex- and most of these have concerned themselves with surface winds. Climatological investigations suggest that wind speeds at the surface are lower in a city than they are in the country and there is some fragmentary evidence of surface inflow into the city under certain weather conditions (Peterson, 1969). Recent tetroon measurements over Columbus, Ohio (Angell, et al 1971) indicate that a city may disturb the flow significantly to heights of at least 200 m.

## 2. Goals

A program designed to delineate the wind field in the planetary boundary layer overlying an urban complex and its rural surroundings was initiated in 1971. The field experiment involved the measurement of mean winds using simultaneous pilot balloon observations from a number of sites in and around St. Louis. During a ten-day period in August these were supplemented by airplane measurements of temperature and winds.

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[1]This work was supported by the U. S. Atomic Energy Commission, Division of Biology and Medicine, U. S. Air Force Air Weather Service and NSF through National Center for Atmospheric Research.

The objectives centered around tests of two hypotheses:

H1. Thermally-induced pressure differences may initiate a "city circulation", with air moving into the city at the surface, rising over the city, and flowing outward to the country at some level aloft [e.g., Lowry (1967), Landsberg (1971)].

H2. Differences in frictional force arising from the dissimilarity in the characteristic roughnesses of the city and rural surfaces may modify the speed and direction of the mean winds and also the intensity of the turbulence.

Answers to some specific questions were sought:

(1) Does the urban complex modify the wind field and if so to what height do significant changes occur?

(2) Does a "city circulation" ever develop and if so under what meteorological conditions?

(3) Does the vertical wind profile change as the air moves over the city and if so are both speed and direction affected?

(4) Do alterations in the wind field, due to either frictional or thermal factors, give rise to local regions of convergence?

## 3. Facilities

From June 15-30 and again from Aug. 1-31, the Air Weather Service of the U.S. Air Force provided 23 men, and the necessary equipment to carry out the pilot balloon observations. Balloons released simultaneously from nine sites in and around St. Louis were tracked by two-man double-theodolite teams. The two observers were linked by land line; the nine teams were linked to a central control point by radio. The readings of both observers, as well as the timing buzz signaling reading time, were recorded on tape recorders hooked into the land line. The angles were transcribed and keypunched in the field and for purposes of quality control, wind calculations were made on the computer at St. Louis University.

The Research Flight Facility of NCAR provided an instrumented Queenair airplane, pilot and technician for this program from August 19-28. Basic measurements were temperature, dew point, wind and airplane position (measurement of turbulence intensity was planned but instrument performance was highly questionable). Temperature was measured by both a Rosemount temperature probe and a platinum resistance thermometer in a reverse flow housing. The dew point was obtained with a Bendix frost point hygrometer. Wind speed and direction are computed from the air speed measured with a pitot system and drift angle and ground speed measured by the Doppler Navigational System. Position is available from both the Doppler System and from photographs of the underlying surface obtained with a downward viewing time-lapsed movie camera.

All measurements were recorded on a digital tape recorder at a rate of 16 per second. Basic data reduction was done on the NCAR CDC 6600 computer.

## 4. Field Operations

A pre-program test was carried out from June 15-30. Although planned primarily as a logistics test, much useful data were obtained. The main experimental period was from August 1 to 31, with a major effort from the 19th to the 28th when the airplane was operated in conjunction with the pibal program.

The pilot balloons were released simultaneously every 20 minutes from nine sites scattered around the metropolitan area for operational periods of roughly three hours. Each balloon was tracked by two theodolites located at the release site. Azimuth and elevation angles from both theodolites were recorded every 20 seconds. The baseline distance between the two observers varied between 1500 and 2500 feet.

The array of release points was variable, selected from the 20 established sites shown in Fig. 1. Many of these locations are compromises - sites suitable for double theodolite observations are not numerous in a city and it is not always possible to obtain permission to use those that are. As a consequence,the nine station array was not always the optimum for the experiment - just the best possible.

The particular array used during any given experiment was based on the hypothesis to be tested and the ambient wind field. Fortunately, the larger scale weather conditions favorable for testing the two hypotheses given in Section 2 are different. Modification of airflow due to frictional effects (H2)

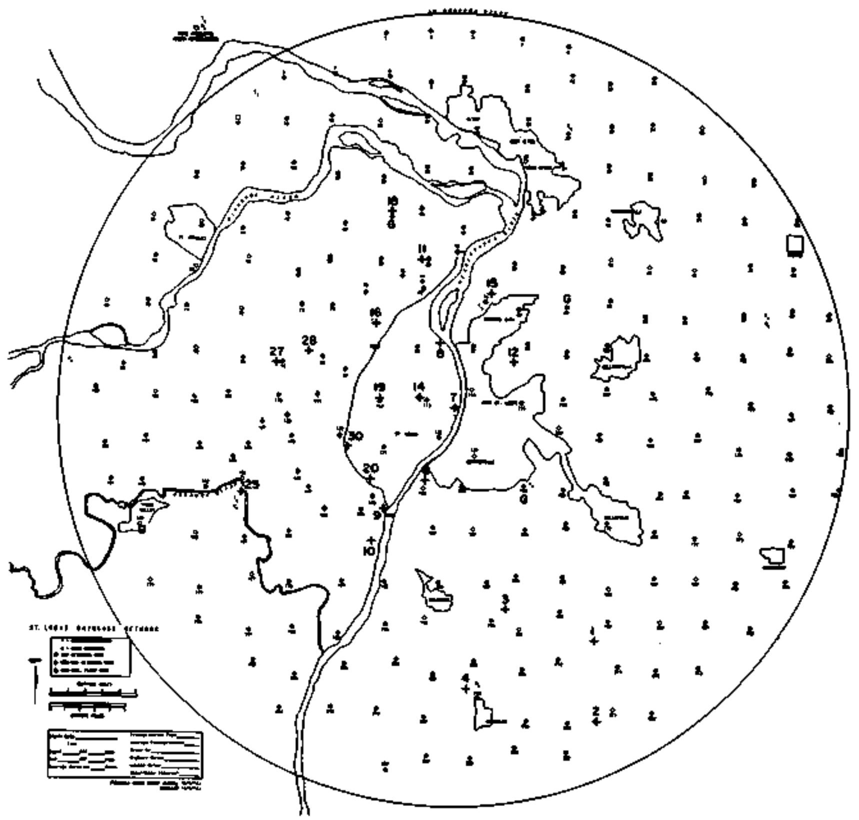

Fig. 1. Pilot-balloon sites used in the Argonne airflow experiments. Locations are shown by the symbol +, with large numbers showing station identification. The base map shows the Illinois State Water Survey rain gage and weather networks.

should be most pronounced when ambient wind speeds are moderate to high, i.e. under fairly strong surface pressure gradients. Thermally-induced city circulations are most likely to occur when the thermal heat island is well developed. This occurs during summer nights under low gradient wind conditions and clear to partly cloudy skies.

Experiments to test for H1 were usually carried out at night. The pibal release points were selected so as to maximize the possibility of detecting inflow into the city and at the same time provide background or "country" conditions. Thus, the array of sites were usually Stations 1,2, 3, and 4, a country box, Stations 7, 9, 30 and 16, a box around the most built-up and industrial part of the city, and station 25 which with stations 16 and 30, or 9 and 30, provided a suburban "triangle". This array will also permit the calculation of net divergence should the measurements prove sufficiently accurate.

Experiments to determine city modification of airflow due to frictional effects usually were carried out during the day although some nighttime observations were also made. To the extent possible, pibal sites were arrayed along the wind with care taken to have stations on both the upwind and downwind side of the metropolitan area. Frequently, the stations were located along two lines in order to provide the opportunity to calculate net divergence over different sections of the urban complex, should the measurements prove sufficiently accurate. A typical site array for a SSW to SW wind utilized stations 10 and 25 (upwind of metropolitan area) 9 and 30 (upwind edge of the city), 19, 7, (mid city), 8 (downwind edge of the city), 11 and 15 (downwind of the metropolitan area).

Airplane tracks were of two kinds. The most common one was a constant level (2000 ft MSL) mapping of the metropolitan area, plus circuits around the main part of the city and around the country box (Fig. 2). This pattern was used on all operations designed to test for the city circulation (therefore all night flights) as well as on some flights when the gradient winds were moderately strong. The second flight pattern (used on only two occasions) was designed to provide "cross-section" information with measurements made on identical straight-line legs at three or four levels (2000, 3000, 4000 and 5500 ft). On one of these two flights two cross-sections were made approximately in the plane of the wind - one over the city, one over the open country to the southeast (Fig. 3a). On the other, one city cross section was made in the plane of the wind and two were made cross wind - one located upwind of the city and the other downwind (Fig. 3b).

The field observations were made primarily during fair weather. Deformation of the wind field by frontal activity or strong convective showers are likely to mask, or at least confuse, the urban disturbance. Also, visual

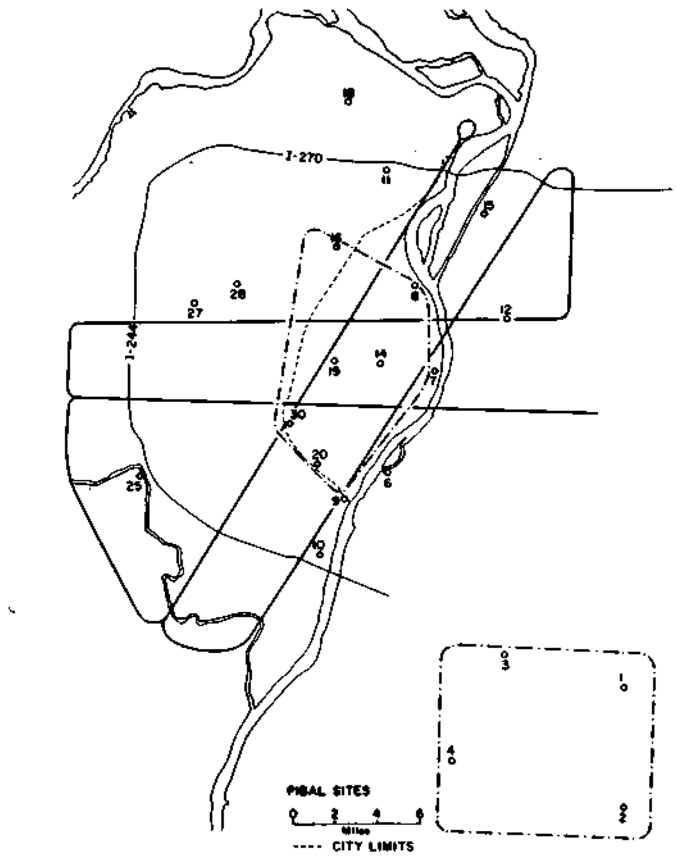


Fig. 2. Airplane tracks used on constant-level flights. Solid lines were straight legs; dot-dash lines show city and country circuits. Pilot balloon sites are also shown.

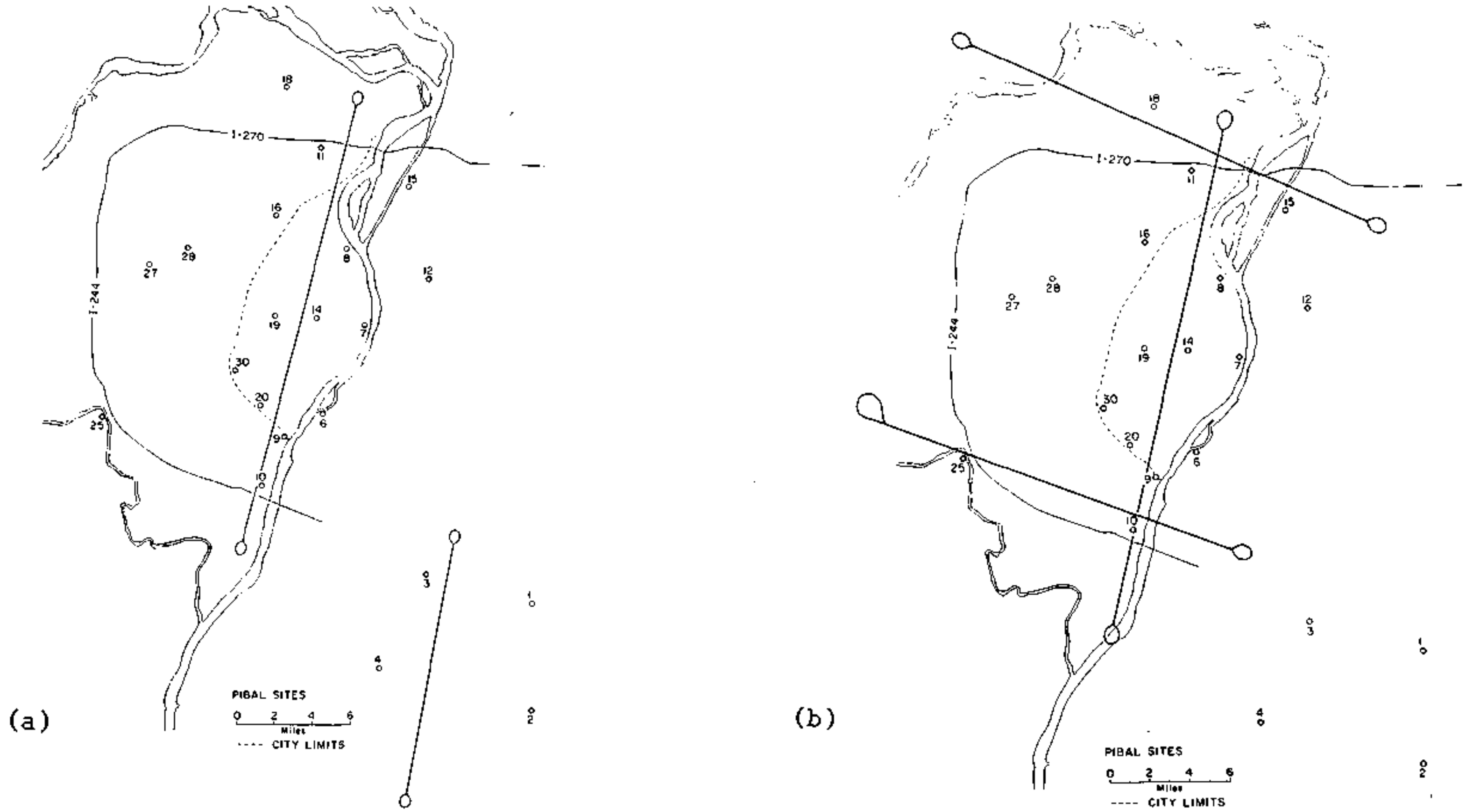


Fig. 3. (a) Locations of cross sections obtained on August 21. Traverses were made at 2000, 3000, 4000 and 5300 ft MSL. Winds in the boundary layer were S to SW.
(b) Locations of cross sections obtained on August 28. Traverses were made at 2000, 3000, and 4000 ft MSL. Winds in the boundary layer were from the north.

tracking of balloons is unproductive when there are low clouds and/or rain.

Both June and August were very "dry" months. As a consequence, the field program was very productive - experimental data were obtained during 21 operational periods in August and nine in June. Table 1 lists all observational periods for both the pilot balloons and the airplane flights.

Eleven scientific flights were made in the 10-day period that the airplane was available. Eight of these were coincident with the pilot balloon observations. A preliminary review of the data indicates that all equipment operated properly except for a special pitot system which was to be used for calculating turbulence spectra. This latter did not produce any usable data.

The analysis of the data is still very much in the basic data-processing phase. However, it is clear even this early that the pilot balloon technique is capable of detecting urban-rural differences in the wind structure in the boundary layer. Moreover, it appears to be sufficiently sensitive to identify small layers of shearing winds. Because of the 20 minute and (3-6 miles) spacing of the pibal soundings, the data will be used in a study of the temporal and spatial variability of the boundary layer winds as well as in the basic study of the deformation of the wind field over a metropolitan area.

The airplane measurements suggest a measurable city effect in the temperature and humidity fields, at least to 2000 ft. The airplane wind data requires additional processing but it appears that these too may show city influence to 2000 ft.

## 5. Future Plans

Subject to continued support from Air Weather Service and NCAR, field observations will be made again for two or three weeks during the summer of 1972. The experiments will be considerably different than those carried out in 1971. The objectives will be to examine the urban-rural differences in turbulence spectra and in momentum and heat fluxes and to examine the relationship between the winds and boundary layer thermal structure.

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Landsberg, H. E., 1970: Man-Made Climatic Changes. Science, 170, 1265-1274.

Table 1. St. Louis Field Operations, 1971

| | Pilot Balloon Observations | | | Airplane Flights | |
|---|---|---|---|---|---|
| Date | Time | No. of Sites | No. of Runs* | Time | Type |
| June 14 | 1100-1320 | 1 | 7 | | |
| 15 | 0220-0420 | 2 | 8 | | |
| 17 | 1100-1340 | 6 | 24 | | |
| 18 | 1140-1340 | 1 | 5 | | |
| 18 | 2300-0120 | 3 | 17 | | |
| 19 | 1100-1320 | 5 | 30 | | |
| 21 | 1040-1300 | 7 | 41 | | |
| 22 | 1040-1320 | 8 | 58 | | |
| 23 | 2300-0140 | 7 | 45 | | |
| 24 | 2240-0120 | 6 | 32 | | |
| 26 | 0940 1220 | 6 | 40 | | |
| 27 | 2240-0120 | 7 | 47 | | |
| 29 | 1040-1320 | 7 | 45 | | |
| August 2 | 1030-1230 | 1 | 5 | | |
| 3 | 1100-1300 | 4 | 16 | | |
| 5 | 1020-1320 | 8 | 56 | | |
| 6 | 1020-1320 | 9 | 66 | | |
| 7 | 1020-1320 | 9 | 67 | | |
| 9 | 1020-1320 | 9 | 69 | | |
| 10 | 1020-1320 | 9 | 65 | | |
| 11 | 2120-0020 | 9 | 63 | | |
| 12 | 2120-0020 | 9 | 65 | | |
| 13 | 2120-0020 | 9 | 67 | | |
| 16 | 2120-0020 | 9 | 64 | | |
| 17 | 2120-0020 | 9 | 66 | | |
| 19 | 1020-1320 | 9 | 61 | 1014-1203 | Constant Level |
| 20 | 1020-1320 | 9 | 65 | 1112-1309 | Constant Level |
| 21 | 1020-1220 | 9 | 32 | 1039-1225 | Cross-section |
| 22 | | NONE | | 2052-2253 | Constant Level |
| 23 | 2120-0020 | 7 | 45 | 1349-1522 | Constant Level |
| | | | | 2122-2353 | Constant Level |
| 24 | 2040-2340 | 9 | 60 | 2011-2314 | Constant Level |
| 25 | 2120-0020 | 9 | 55 | 2105-0004 | Constant Level |
| 26 | 2120-0020 | 8 | 59 | 2056-2353 | Constant Level |
| 27 | 1320-1620 | 8 | 56 | 1305-1630 | Constant Level |
| 28 | | NONE | | 1216-1401 | Cross-section |
| | | | | 1516-1716 | Instrument |
| 30 | 1100-1400 | 5 | 43 | | |
| 31 | 1020-1320 | 6 | 53 | | |

*Soundings to at least 300 m

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# ARGONNE RAIN SCAVENGING STUDIES IN METROMEX-1971[1]

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## 1. Introduction

Wet deposition of atmospheric particulate matter, i.e., deposition in rain and snow, is one segment in the system of pathways by which environmental radioactivity reaches man. To assess more accurately the impact of environmental radioactivity on man, better predictions of all forms of environmental transports, including wet deposition, are needed.

Wet deposition requires that the deposited material must become associated with a raindrop (or snowflake) sometime during its airborne lifetime. At the same time, if urban atmospheric pollutants modify precipitation processes, it seems likely that they must first become part of these processes, by entering cloud or precipitation elements. Thus, by considering urban pollutants as tracers for radioactivity, and studying their wet deposition, we may be able to both (a) improve our ability to predict wet deposition of all kinds of pollutants, including radioactivity, in areas of high population density, and (b) shed light on a possible cause of inadvertent precipitation modification in urban areas—the focus of the METROMEX project.

## 2. Goals

The general goal of this work is to improve the prediction and understanding of the rain scavenging of atmospheric particulate matter. Specific goals of the 1971 field work were:

(1) Measurements of washout ratios (g element per kg rain/g element per kg air) for approximately 10 elements, from daily rain and air filter samples.

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(1) This work sponsored by the U.S. Atomic Energy Commission, Division of Biology and Medicine.

(2) Evaluation of the validity of using concentrations in air measured near the ground to compute washout ratios, by comparison with concentrations measured at 2000-3000 ft. above ground using aircraft, and

(3) Measurements of the size distributions of the 10 elements.

3. Facilities

Nearly all of the field facilities for this work are used to collect samples. These may be grouped into two general types—aerosol samplers and rain samplers.

High-volume (~ $40 m^3$ /hr) filter samplers were used to collect aerosols near ground level on 11-cm diameter Whatman-41 filter paper. Aerosol collections for size distribution determinations were made using 8-stage Andersen impactors. The small vacuum pumps used to draw air through the Andersen samplers were also used for occasional short period (2-10 hr.) filter sampling on 2.5 cm diameter Whatman-41 paper. Airborne filter samples were collected on IPC-1478[(2)] paper, using LASL (Los Alamos Scientific Laboratory) samplers aboard U. S. Air Force RB-57C aircraft.

Daily rain samples were collected by 10-inch polyethylene funnels drained into polyethylene bottles. Sequential rain samples were collected in automatic samplers described by Gatz, et al. (1971).

4. 1971 Operations

Samples were collected at four locations near St. Louis and at the Pere Marquette radar site of the Illinois State Water Survey. The four stations are identified on the map in Fig. 1 as Tyson, Coldwater Creek, KMOX, and Centreville, together with the types of samples collected at each. In general, the locations were chosen so that one or more stations would be upwind of St. Louis, and one or more downwind, in terms of both the low altitude air flow and storm motion, for most weather situations.

The summer field work was carried out during two main operational periods, 16 June to 2 July and 2-31 August. Between these periods additional sampling was carried out, primarily at the Pere Marquette radar site, by personnel of the Illinois State Water Survey. Routine sampling was done on a seven-days-per-week basis.

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(2) Filter paper specifically formulated by International Paper Co. for high-altitude nuclear debris sampling from aircraft.

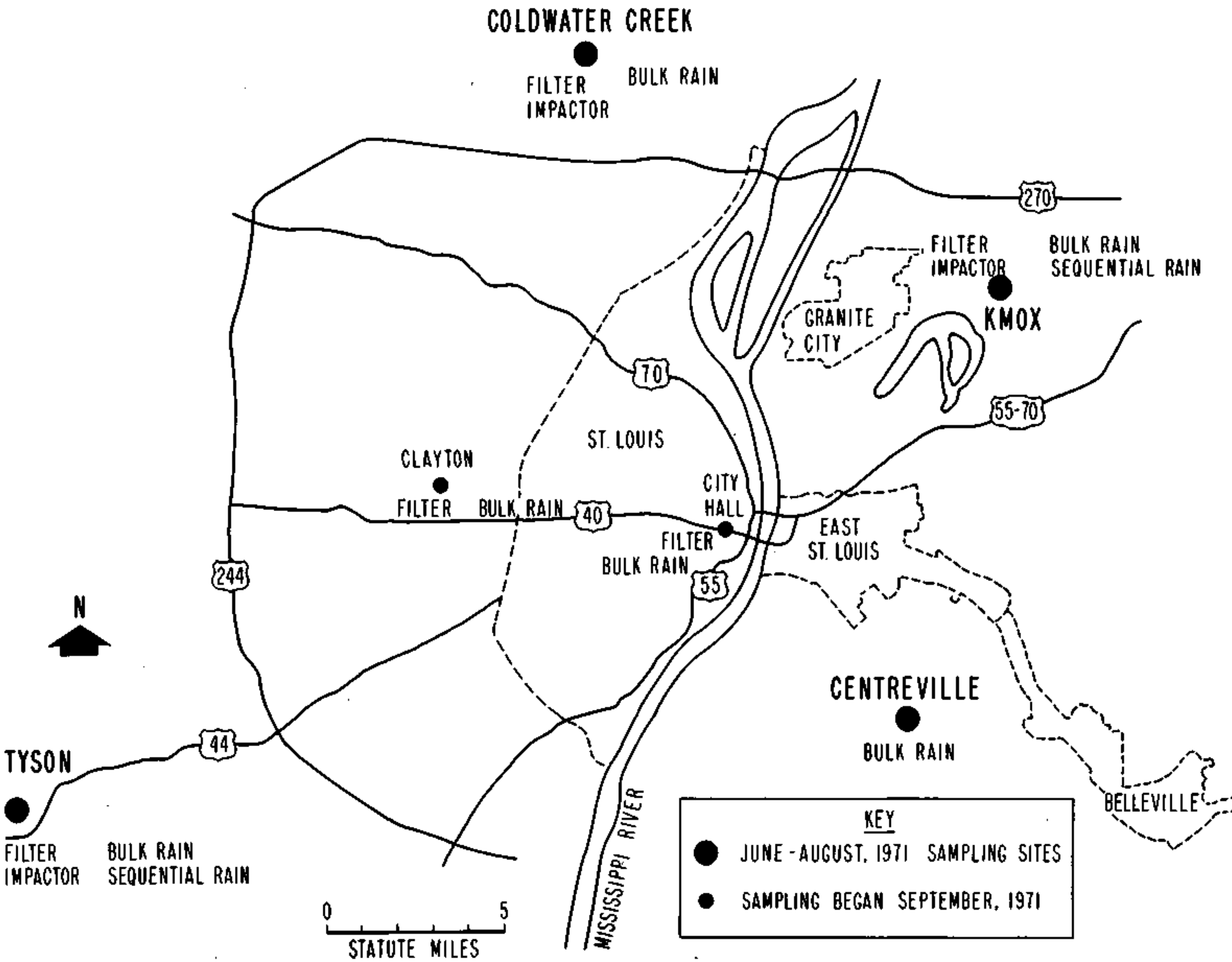



Fig. 1. Map of St. Louis area showing Argonne ground-level air and rain sampling stations, summer and autumn, 1971.

Fig. 2 shows collection dates or periods for the various kinds of samples and other data collected. Beside the kinds of samples already mentioned, the figure shows when short-period (2-10 hr.) Whatman-41 and IPC-1478 filters were exposed near the ground for comparison with aircraft filters. Also shown is a single high-altitude thunderstorm outflow sampling mission, conducted in the Albuquerque, New Mexico, area.

Additional sampling was carried out from September through November, 1971, at two sites (designated "City Hall" and "Clayton" in Fig. 1) in the St. Louis area. Daily and weekend air filters and precipitation samples were collected at these two locations.

Rain samples were filtered in the field usually within several days of collection to separate soluble and insoluble fractions. Filtrates were stored frozen to minimize possible losses of trace metals to walls of the sample containers.

Sample analyses will concentrate primarily on cadmium, calcium, copper, iron, lead, magnesium, manganese, potassium, sodium, and zinc. Analyses will be performed primarily on a newly-installed Instrumentation Laboratory Model 353 atomic absorption spectrophotometer. Additional elements will be determined later using neutron activation analysis, especially for comparison of aircraft and ground-level filter samples.

## 5. Results

Results to date are limited to careful checks of the accuracy and reproducibility of the analytical procedures for the various kinds of samples. These efforts have been very successful so far. They are nearly completed now, and sample analysis will begin soon.

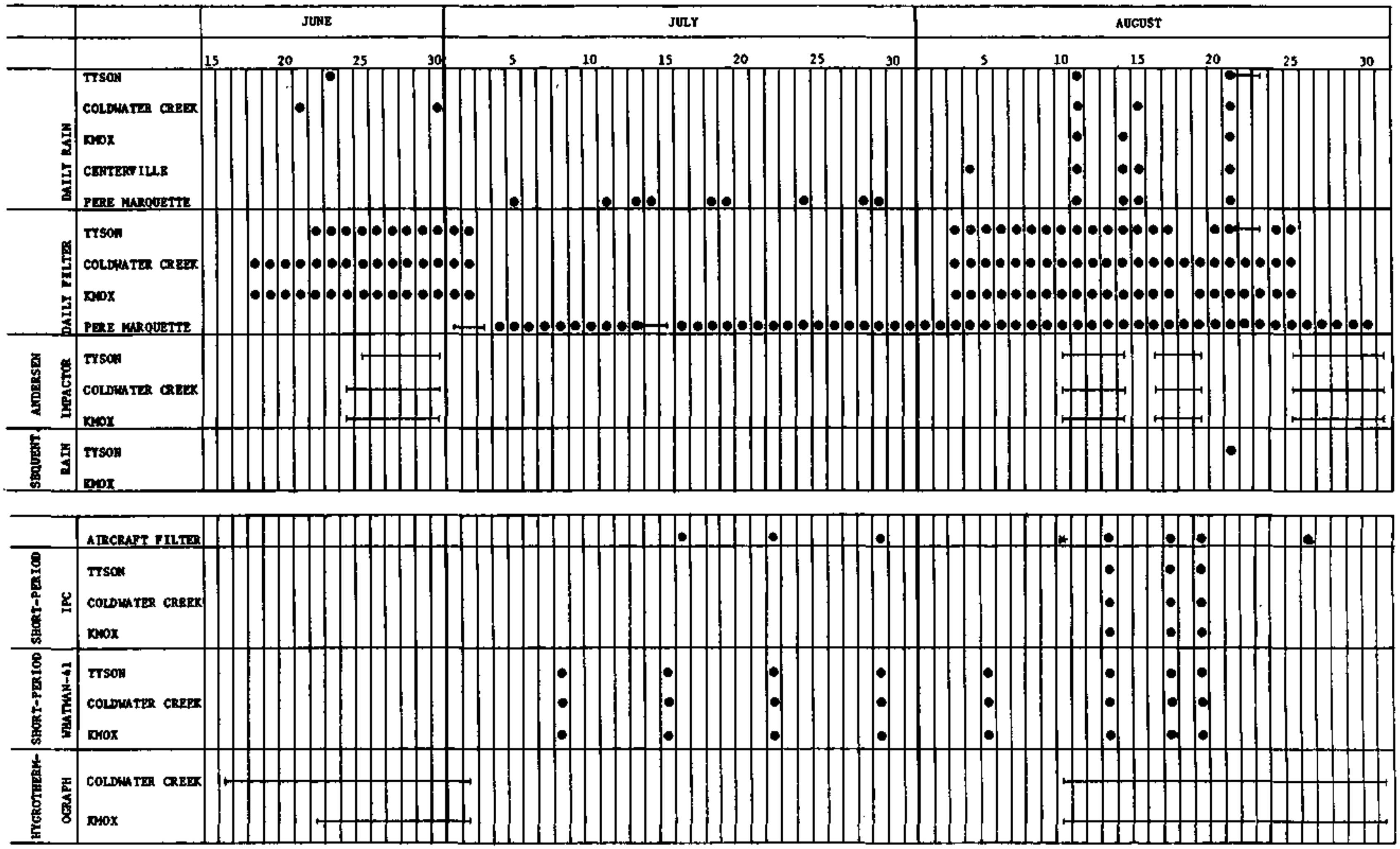
## 6. Plans

Plans for 1972 are still indefinite. My level of participation will depend heavily on progress in sample analysis and interpretation of results and the availability of funds and personnel. Tentative plans call for operation of several (about 4) stations collecting daily rain and air filter samples, and occasional impactor samples. A 2-3 week period of intensive effort, probably in July or August, may be devoted to investigation of a problem of special pertinence; e.g. , the vertical distribution of pollutant concentrations. The participation of filter-sampling aircraft is desirable, but also uncertain at this point.

## 7. References

Gatz, D. F., R. F. Selman, R. K. Langs, and R. B. Holtzman, 1971. An automatic sequential rain sampler. J. Appl. Meteor., 10 (2), 341-344.

Fig. 2. Sample collection chart for Argonne rain scavenging studies in The St. Louis METROMEX Project, 1971.




● Single sample, 24 hr or less in duration.

├──┤ Continuous sample or record longer than 24 hr duration, showing days of beginning and end.

* Thunderstorm anvil outflow and ambient background sampled separately by two aircraft near Albuquerque, N. Mex.

# UNIVERSITY OF CHICAGO IN METROMEX

Roscoe R. Braham, Jr.
Cloud Physics Laboratory

## 1. Introduction

The University of Chicago Cloud Physics Laboratory brings to Metromex a group of scientists skilled in studies of the physics of clouds using radar, airplanes and laboratory experimentation. The Chicago group is supported by the National Science Foundation under grants GA 20470 and GA 28190X.

Surface weather records strongly suggest that areas of increased rainfall and severe storms are frequently found downwind of urban-industrial complexes. To understand these effects and better assess their significance one must examine various physical processes which might help to relate specific weather phenomena to particular aspects of the urban complex. Obviously clouds are somehow involved. Conceivably, increases in rain could come about because the city induces more clouds to form, or existing clouds to grow larger. Perhaps the city changes the internal character of clouds (drop spectra, etc.) so as to cause rain to be heavier but somewhat slower forming. Alternatively, if clouds are gradually slowed up as the clouds cross the city, we could get a downwind rain max because of the convergence effect (as cars jam up at a traffic obstruction). Or if the city promotes the formation of downdrafts as clouds move across it, the result could be a downwind rain maxima. To obtain measurements about the clouds over and downwind of the city, for comparison with upwind clouds, the University of Chicago Cloud Physics Laboratory has undertaken a program of cloud physics type studies as a part of METROMEX.

## 2. Objectives

The main objectives of the University of Chicago group during the 1971 Metromex operations were:

a) Measure cloud condensation nuclei and ice nuclei to determine the extent to which the city effluent may be a source for these particles or may poison previously existing ones. Cloud condensation nuclei (CCN) are essential for cloud drop formation; cloud ice nuclei (CIN) are involved in snow formation.

b) Measure cloud drop spectra to determine whether clouds over and downwind of the city differ from those upwind, and if they do whether this difference is relatable to the nuclei measurements.

c) Map precipitation at the ground and aloft in the clouds using a Height-Finder radar.

d) Measure the size and extent of the city "plume" in so far as it is revealed in air temperature, air humidity and aerosols.

## 3. Facilities

The University of Chicago group in METROMEX operates from the Municipal Airport at Greenville, Illinois under lease agreements with the Greenville Airport Authority and their fixed base operator. Located about 45 mi NE of St. Louis, and about 35 mi from the area of "maximum" effects shown by Changnon in his earlier studies, Greenville has proven to be an ideal location for our radar and base of operations for our cloud physics plane. This airport is large enough to support our flight operations yet not so crowded as to make operations cumbersome. The radar is located on a small wooden tower only a few feet away from the airplane parking ramp and field laboratory building. The flat terrain around the Greenville Airport provides an obstruction free horizon for the radar. Also a factor in selecting Greenville for the University of Chicago radar was its position downwind of St. Louis enabling us to cover the possibility that the "Urban" effects extend farther downwind than was first suggested in the Changnon analysis.

University of Chicago cloud physics plane.-- The University of Chicago cloud physics research plane (Lockheed Lodestar N9980F) is an essential tool in our research. With its present instrumentation this plane has a practical ceiling of about 27,000 ft; max. duration of about 6 hours; cruising speed for data collection about 130 kts; and it has about 340 amp 28 VDC for scientific instrumentation. This plane is leased from, and operated for us by Interstate Airmotive Corp., LambertField, St. Louis. Major items of scientific instrumentation and important auxilliary equipment are listed in Table 1.

University of Chicago ground radar.-- The radar of major use at present in an AN/TPS-10, 3-cm, RHI radar housed in a hiway trailer with the antenna (and some electronics) mounted on a 30 ft high tower. The TPS-10 uses a 10 ft by 4 ft "orange peel" antenna giving a beam 0.7 deg in the vertical and 2.0 deg in the horizontal. The antenna wobbles vertically once very second while rotating horizontally once every three minutes. The result is a series of vertical radar cross-sections at successively different azimuths; three minutes being required to complete one 3-D look at the entire sky.

The second radar is an SPS-4, 5-cm, 250 Kw set originally used as a Navy search radar. We have it mounted in the radar trailer connecting to a six feet diameter parabolic dish mounted on the trailer roof. The axis of this beam is fixed in the vertical position giving time-height data on clouds passing overhead. At a future date we anticipate replacing this dish with one that scans in the RHI mode.

Other facilities.-- At the Greenville Airport the University of Chicago Cloud Physics group leases about 1,000 sq ft in an airplane hangar for use as a field office and laboratory for equipment maintenance, photography development, data analysis, etc.

The major facilities of the University of Chicago Cloud Physics Lab are on campus in Chicago. There the group occupies half the fifth floor of the Hinds Geophysical building. Facilities include three large labs (atmospheric chemistry, cloud particle physics, ice physics), large data analysis room, electronics laboratory, and smaller rooms for film analysis, library, photographic dark room, electron microscope laboratory and officea In the roof penthouse is a 7500 cfm wind tunnel. A walk-in cold room provides space for studies of ice.

Scientific equipment in the lab includes nuclei detectors of various types, drop freezing equipment, electron microscope and shadowing equipment, cameras, microscopes, solid state electro-optical research equipment, microwave test equipment, Kahn electrobalance, UV spectrophotometer, and various other laboratory and data analysis equipment.

Other University facilities available to the project are computers (IBM 7094 and 360), shops, library, and photographic facilities.

## 4. Operations during 1971

The Chicago group was in the field during July and August 1971. Table 2 summarizes the dates and times of data taking operations. Measurements began 12 July with flight 65 and ended with flight 103 on 31 August. Six flights were devoted to clear air cross-sections; nine to cloud sampling over St. Louis; five to aerosol sampling only and the remainder to cloud flights supporting research other than METROMEX.

During a two week period of July we also had use of an NCAR QueenAir 306D and a leased Aeronica. Flights with these planes were primarily in support of Ph D research by John McCarthy, graduate student at Univ. of Chicago.

A key factor in the success of an operation such as METROMEX is the ability to secure flight clearance over the city at times and altitudes dictated by the research needs. Anticipating the need for careful coordination with other air space users we organized a meeting at which representatives of Federal Aviation Authority and Air Force traffic controllers (Scott Field) met with representatives of all scientific groups planning to take data from airplanes flying over St. Louis. The meeting was held at the St. Louis FAA Tower on 14 April 71 under the chair of Mr. Ralph Murkin. Using procedures worked out at that meeting, and subsequent contacts, it was possible to complete most clear air Metromex flights in accordance with the dictates of the research. Cloudy weather flights presented a more serious problem, obviously calling for further discussions. All Univ. of Chicago flights were conducted in accordance with FAA regs.; no effort was made to obtain waivers.

## 5. Preliminary Results

Cloud Nuclei.-- Of the various measurements made during July-August 1971 only those involving Cloud Condensation Nuclei have been analyzed sufficiently to permit reasonable positive statements about the findings.

Between 19 July and 31 August CCN collections were made on 19 upwind-downwind pairs of air samples. The air samples were collected from the plane and stored in 100 liter aluminized Mylar bags for return to the ground where they were analyzed in a thermal diffusion type counting chamber to determine CCN concentration as a function of supersaturation. Measurements were made at five values of supersaturation between 0.18 and 1.0 per cent. The samples of each pair were collected only 10 to 15 minutes apart and at the same altitude. Immediately after obtaining the second sample of the pair, the plane returned to ground where the samples were processed immediately, usually within 30 minutes. A small correction was applied for bag losses prior to processing.

At a supersaturation of 0.18 per cent 16 of the 19 downwind samples had higher concentrations of CCN than their companion upwind sample, the average increase being 54%. At 1.0 per cent all downwind samples showed the greater CCN concentrations, the average increase being 95%. The average concentrations ($cm^{-3}$) of nuclei active at 0.18% were 712 upwind, 1043 downwind; at 1.0% they were 2209 and 3887. A plot of average concentration of cloud condensation nuclei upwind and downwind of St. Louis, for these 19 cases, is shown in Fig. 1. The fact that St. Louis was a source of cloud nculei during the summer of 1971 thus has been demonstrated.

Next we must move to a systematic study of how these nuclei affect cloud microscructure, and subsequently precipitation and severe storms. At this point it is instructive to consider the results of recent Ph D thesis research by a University of Chicago student, Mr. James Fitzgerald. Mr. Fitzgerald improved upon previous computer models relating cloud updraft and subcloud nuclei spectra to the cloud base drop spectra. This theory was checked and verified by field measurements in Minnesota and Florida. An example of the extent to which this theory predicts cloud base drop spectra from measurements of sub cloud condensation nuclei spectra and updraft is given in Fig. 2 (taken by permission from Mr. Fitzgerald's thesis). Considering the upwind-downwind CCN data against the background of Fitzgerald's thesis we would predict that clouds forming over and downwind of the city, and ingesting the city produced CCN, would have base regions characterized by higher concentrations of smaller droplets as compared with those forming upwind. Our second objective permitted checking this prediction.

Cloud drop spectra.-- Measurements of cloud drop spectra in clouds upwind and downwind of St. Louis were carried out on several flights by making use of the continuous Formvar replicator and the optical array probes. To make use of the Fitzgerald model we must restrict ourselves to spectra measured 500 to 1000 ft above the cloud base, i.e., above the zone of activation of cloud nuclei. The somewhat reduced number of cloud days this past summer, and difficulties in obtaining traffic clearances on occasional days of low ceilings reduced the amount of low cloud and cloud base spectra data obtained.

Reduction of the array probe data has been delayed by a problem in the base station at NCAR (where our air data tapes are converted to computer tapes). Reduction of data from the replicator is in progress. Thus far spectra from 11 cumulus type clouds on Flight 100 have been determined. Simultaneous wind measurements obtained by Dr. Bernice Ackerman of Argonne National Lab (one of the four cooperating groups on Metromex) showed that 5 of these 11 clouds were upwind and 6 downwind of St. Louis and its environs. The average drop spectra for these clouds are given in Fig. 3. The contrast is striking. The downwind clouds did indeed contain many more and much smaller drops compared to upwind clouds of the same type for the same date and time. In the language of the cloud physicist we would say that the downwind clouds are more "continental" than their upwind counterparts. Heretofore continentality has been associated with reduced likelihood of coalescence rain, and therefore reduced likelihood of rain from small clouds; and increased likelihood of Bergeron precipitation with other big cloud characteristics such as hail ans severe weather. This projection seems at variance with the Illinois Water Survey finding that the city induced rainfall maximum is very close to the city, and gives rise to the hypothesis that the close-in effect may be due to dynamical influences of the city while the cloud physics effects may produce a downwind zone of decreased rainfall and increased hail and severe weather. This hypothesis must form the bases of studies in succeeding summers.

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Delineation of the "City Plume".-- The most expensive type measurements made by the Chicago group -- expensive in terms of flight hours expended, computer reduction time and post-flight analysis effort -- were the series of low level cross sections flown across the city to help delineate the plume of air showing a direct influence of the city. This influence can take many forms, e.g., the heat island immediately over the city. Thus far these analyses have concentrated on the "heat island" which we find measurable, at least to 2000 ft above the city, both on the early morning and mid afternoon flights. Examples are shown in Figs. 4 and 5.

Fig. 4 shows reverse-flow temperature data measured on a series of E - W passes directly over the city between 1303 and 1418 CDT on 23 August, 1971 (Flt. 94), during a period agreed on in advance as one of all-out effort by all of the Metromex cooperating groups. Fig. 4 extends from the Maryland Heights Vortac (along the Missouri River, near Chesterfield, Missouri) to a point 35 n. mi. east (northwest of 0'Fallon, Ill.). Soundings for both ends of the section are shown at the right. Temperature data within the section are referenced to the values measured at the west end of the section and have been reduced to common pass altitudes to correct for minor altitude variations along any given pass.

Two points stand out in this section. A heat island of about 1 deg is found at the lowest level of flight over the city about 1,000 ft agl, while at 2,5000 agl it is about 0.6 to 0.7 deg. The mesoscale synoptic temperature pattern is shown in the pass at 4,500 agl. The low level winds during this flight period were essentially calm.

Fig. 5 is another example of a vertical section over the city. This one represents temperature data for the period 0619-0749 CDT on 24 August 1971 (Flt. 96). The style of presentation is identical with that of Fig. 4. The section extends from a 10 n. mi. northwest of the St. Louis Vortac (a point between the Mississippi and Illinois Rivers near Brussels, Ill.) to 30 n. mi. southeast of the Vortac (a point just west of Belleville, Ill.). The section crosses the Mississippi River about 2 n. mi. NW of the Vortac, the Missouri River at 3 n. mi. SE, thence across Lambert Field and the city of St. Louis to re-cross the Mississippi near the Arch at 20 n. mi. SE.

In this section the heat island shows very distinctly at the two lowest levels of flight (ca 1,000 and 1,500 agl). At the 1,000 ft level it shows as two distinct maxima, one just downwind of St. Charles, Mo., and the other over St. Louis. The maximum difference at the 1,000 ft level is 1.8 deg, and at the 1,500 ft level is 0.9 deg, referenced to the northwest end of the section. Referencing to the opposite end would give smaller values. The wind direction during this flight was listed as calm by the Weather Bureau but was observed to be from the southwest during the Flight.

## 6. Future Plans

The University of Chicago Cloud Physics Laboratory anticipates continued involvement in METROMEX. We plan to carry out studies of nuclei, cloud drop spectra, cloud condensation nuclei, ice nuclei, cloud particle spectra (both liquid and solid), the city plume and precipitation mapping during a 4 week period in Jan-Feb, 1972 and for two months during the summer of 1972. We hope to more clearly define the city as a nucleus source, to more thoroughly delineate the downwind plume, and to more firmly establish upwind-downwind differences in cloud microstructure, all as a function of meteorological conditions. Our operations will continue to be based at the Greenville Airport.

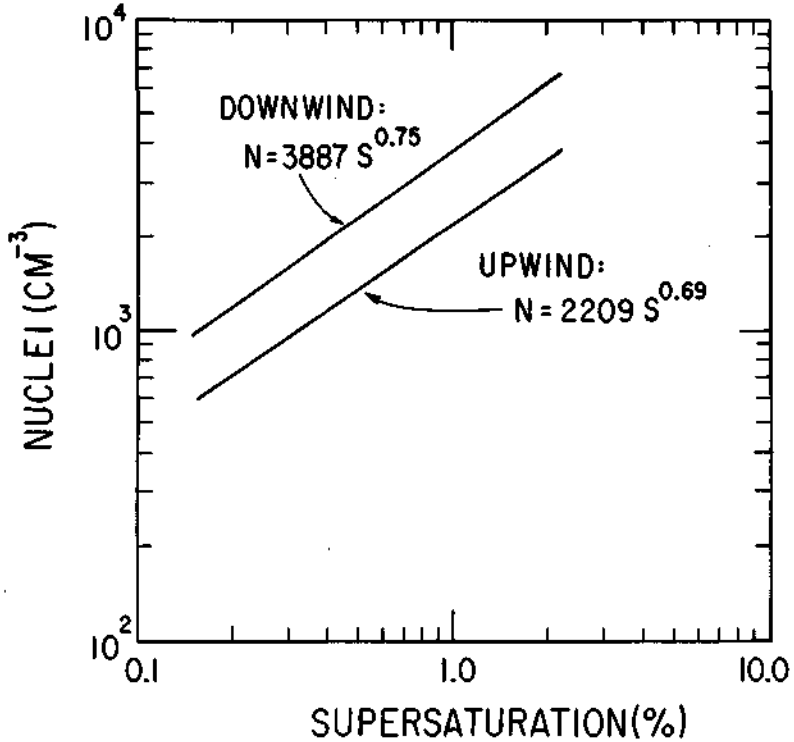


Fig. 1 Average upwind and downwind spectra of cloud condensation nuclei.

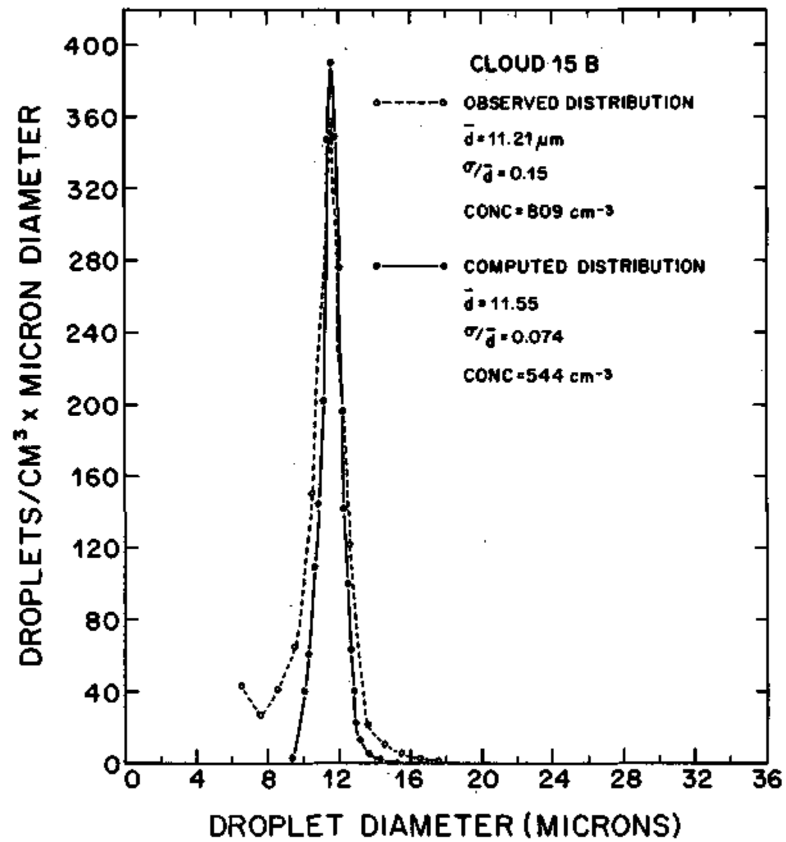


Fig. 2 Example of observed versus model predicted drop spectra at cloud based - - from James Fitzgerald's Ph D Thesis.

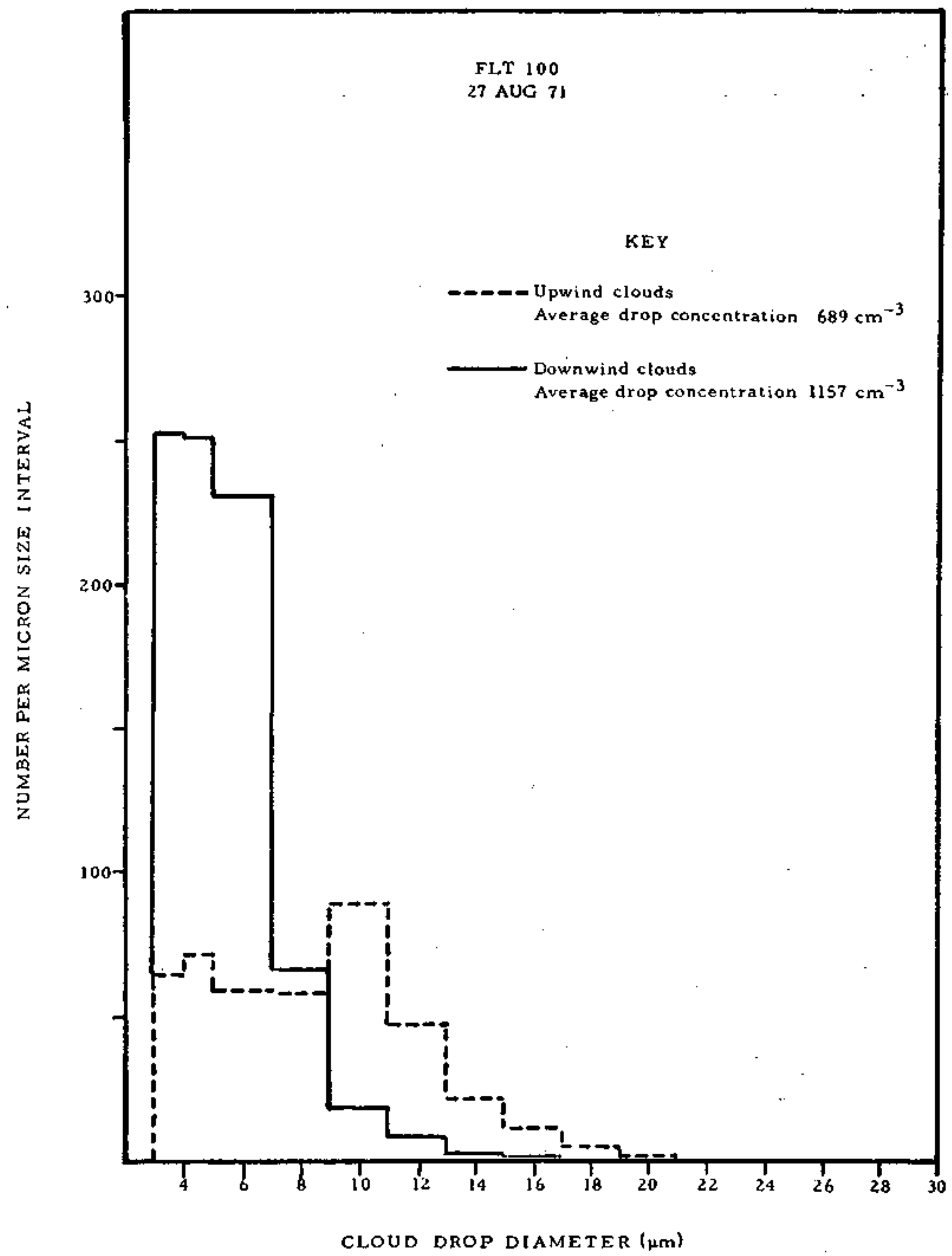


Fig. 3 Comparison of upwind and downwind cloud drop spectra. Flight 100, 27 Aug 1971.

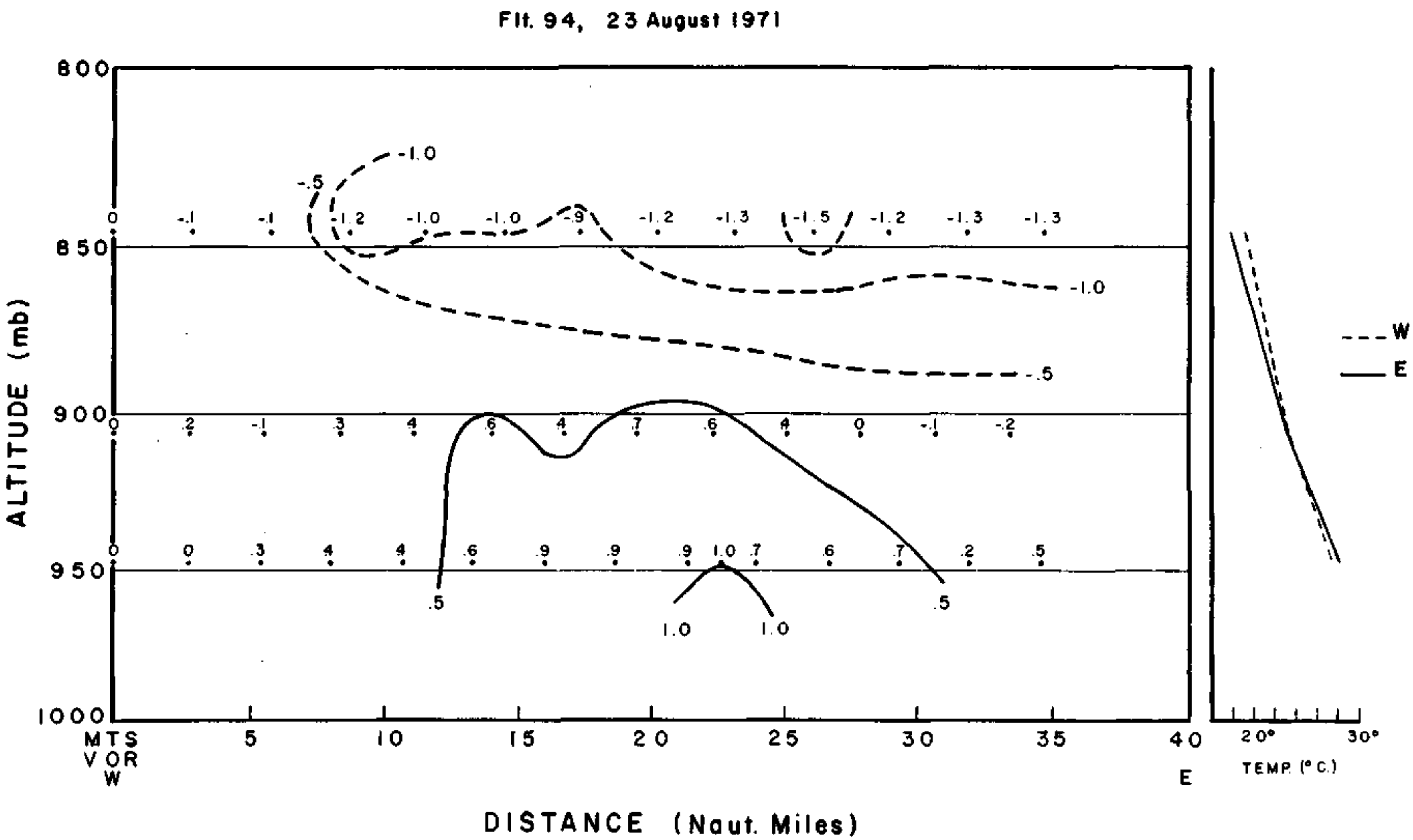


Fig. 4. Vertical Cross Section over St. Louis, Mo., 1303-1418 CDT, 23 August 1971.

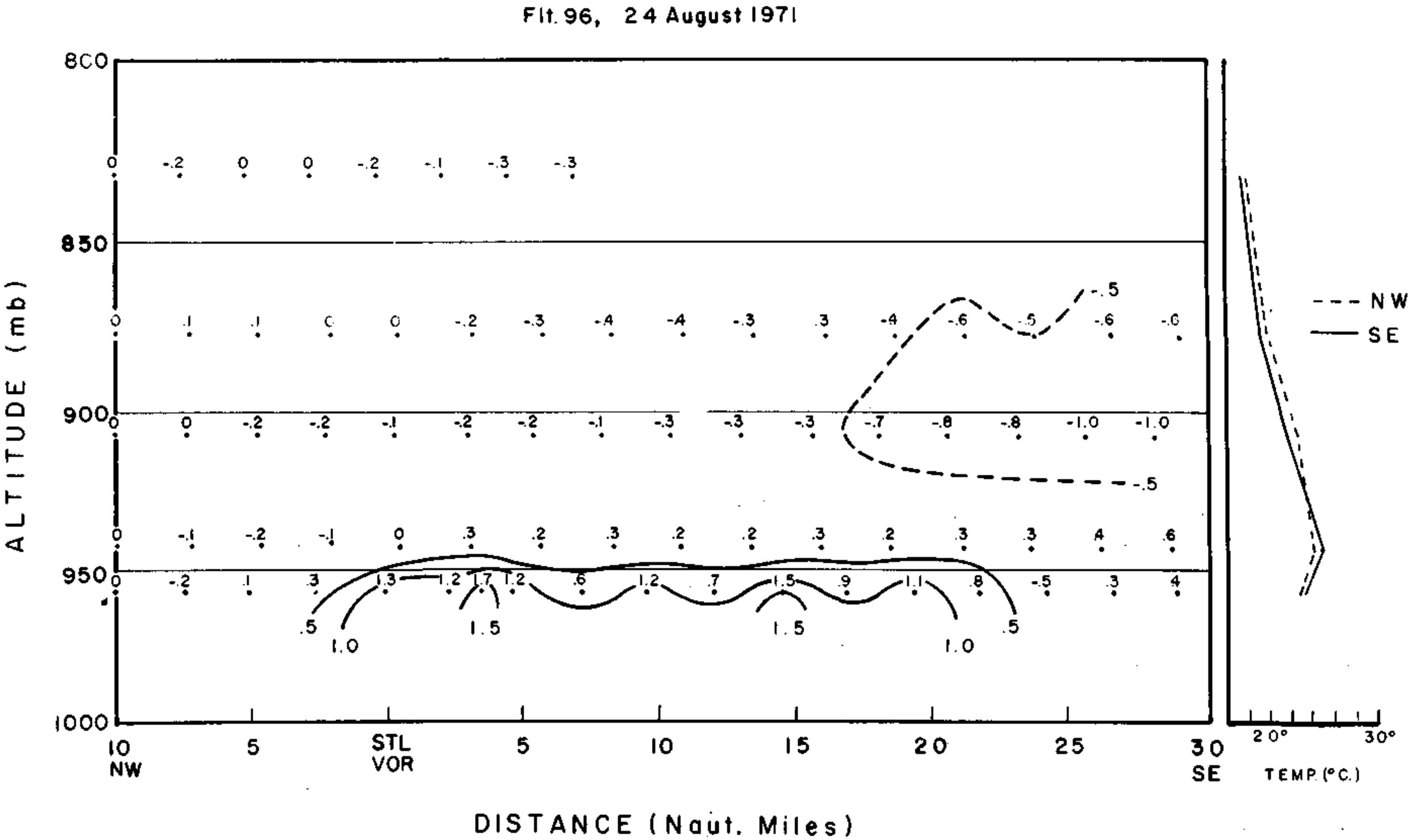


Fig. 5. Vertical Cross Section over St. Louis, Mo., 0619-0745 CDT, 24 August 1971

Table 1. Lodestar N9980F Instrumentation

| Parameter | Instruments |
|---|---|
| Cloud particle spectra | Knollenberg optical array probes with real-time readout<br>Extinction probes with real-time readout<br>Continuous Formvar replicator |
| Precipitation spectra | Optical array samplers with real time readout<br>Lead foil sampler (see note 1)<br>Sampling tube and sampling station |
| Liquid water content | Johnson-Williams heated wire<br>Australian paper-tape (see note 1)<br>Computer integration of optical array spectra |
| Radar | Bendix RDR-lBl, 3-cm, 40 Kw, nose mounted, 360 deg scan |
| Air temperature | Rosemount total temperature<br>Platinum elements in two different types of reverse flow housings |
| Air density | Pace Pl (0-15 psi) variable reluctance sensor close coupled to CD 32 carrier-demodulator with attached temperature sensor to allow correction for temperature coefficient |
| Humidity | Bendix Frostpoint hygrometer DHAA-1P |
| Optical radiation | Upward and downward facing, hemisphere viewing pyranometers (Moll-Gorczynski type) (See note 2) |
| Aerosol and nuclei sampling | Extinction probe without size scaling for total aerosol<br>Manifold of 24 Millipore filters sequentially exposed on command<br>Sampling port for "grab" samples |
| Airspeed | Pace Pl (± 2 psi) variable reluctance system |
| Attitude | Standard aircraft gyros |

Table 1. (Continued)

| Parameter | Instruments |
|---|---|
| Magnetic heading | C-2, Gyrosyn compass |
| Position indicators | Dual 0MM1 with OBI; dual ADF DME and ATC beacon |
| Communication | Dual VHF Collins 51V; Dual UHF Collins 51V; Multicom transceiver for plane to project radar |
| Time sychronization | Crystal oscillator, temp. comp., 1 / $10^8$ with binary freq. $2^{21}$, counted down to hours, minutes, and seconds; also used to drive counters and cameras. |
| Data recording | Multichannel analog and digital magnetic tape system adapted from NCAR ARIS II.<br>Oscillograph recorder, Consolidated Visicorder<br>Photobox with 16mm time-lapse photography<br>Uher voice-actuated magnetic tape for ship's intercom |
| Cloud photography | 16mm Flight Research Multidata camera in lapse time mode, forward facing<br>Hand held 35mm cameras |

Note 1. Present plans are to remove this device before the 1972 flight program.

Note 2. Not available during the 1971 flight program.

Table 2. Operations Summary, 1971. University of Chicago Cloud Physics Laboratory

| Date | TPS-10 films | Flight: No.<br>T.O.; Lndg | Flight Mission | CCN Bags Location | Ice nuclei millipores |
|---|---|---|---|---|---|
| 12 July | 1506<br>1535 | 65<br>1337<br>1525 | Three plane with NCAR 306D and 72X for laying smoke rings around cu. | | |
| 13 July | | 66<br>1406<br>1645 | Two plane with NCAR 306D. Two level passes through 10 cu. | | |
| 15 July | 0926<br>1730 | 67<br>1410<br>1745 | Two plane with NCAR 306D. 17 two level passes thru 10 cu | | |
| 17 July | | 68<br>1439<br>1746 | Two plane with NCAR 306D. 14 two level passes thru 9 cu | | |
| 19 July | | 69<br>1541<br>1815 | Two plane with NCAR 306D.<br>METROMEX CROSS SECTIONS<br>306D 030-210 rad TOY<br>80F 210-030 rad STL | 1 upwind<br>1 downwind | 23 |
| 22 July | | 70<br>1925<br>2112 | Aerosol measurements in power station plume | | |
| 23 July | 1211<br>2110 | 71<br>1441<br>1605 | Aerosol sampling | 1400 ft ovr GRE | |
| 24 July | | | | Gnd sample GRE | |
| 27 July | | 72<br>1023<br>1230 | Smoke pattern study using 72X | 1 upwind<br>1 downwind | 55 |

Table 2. Con't.

| Date | TPS-10 films | Flight: No. T.O.; Lndg | Flight Mission | CCN Bags Location | Ice nuclei millipores |
|---|---|---|---|---|---|
| 27 July | | 73<br>1433<br>1842 | METROMEX Cross-sections TOY and STL 040-220 | | |
| 28 July | 0908<br>1024 | 74<br>1433<br>1706 | Cirrus sampling<br>44 sample slides | | |
| | 1122<br>1449 | | | | |
| 30 July | | 75<br>1040<br>1417 | METROMEX Cross-sections TOY and STL 040-220 rads. | 1 upwind<br>1 downwind | 48 |
| 2 Aug | 1102<br>2102 | | | | |
| 4 Aug | | 76<br>1031<br>1110 | Particle probe sampling | 2500 and 700 over GRE | |
| 4 Aug | | 77<br>1338<br>1532 | METROMEX cloud flight box pattern around city and run across in plane of wind | 1 upwind<br>1 downwind | 10 |
| 5 Aug | 1545<br>2125 | | | | |
| 6 Aug | 1347<br>1435 | 78<br>1610<br>1728 | Aerosol collections | 1 upwind<br>1 downwind | |
| 9 Aug | 1145<br>2105 | 79<br>1305<br>1740 | METROMEX Cross-sections TOY and MTS 130-310 rads | | 56 |

Table 2. Con't.

| Date | TPS-10 films | Flight: No.<br>T.O. Lndg | Flight Mission | CCN Bags Location | Ice nuclei millipores |
|---|---|---|---|---|---|
| 9 Aug | | 79A<br>1807<br>1838 | Cloud Condensation Nuclei Sampling | 1 upwind<br>1 downwind | |
| 10 Aug | 2108<br>2245 | 80<br>0412<br>0936 | METROMEX Cross-sections 320-140 rads on STL at sunrise | 1 upwind<br>1 downwind | 78 |
| 10 Aug | | 81<br>1353<br>1706 | Two plane with 72X<br>Ex cu about 90 mi east GRE | | |
| 11 Aug | | 82<br>1219<br>1522 | Two plane with 72X<br>Ex cu Central Tenn. | | |
| 11 Aug | | 83<br>1622<br>1938 | Return GRE from Dyersburg, Tenn. | | |
| 13 Aug | 1434<br>1454 | 84<br>0739<br>0827 | Speed runs | | |
| | 1750<br>1852 | 85<br>1150<br>1247 | Aerosol sampling | 1 upwind<br>1 downwind | |
| 13 Aug | | 86<br>1527<br>1827 | METROMEX cloud base sampling - box around city | 1 upwind<br>1 downwind | |
| 14 Aug | 0936<br>1107 | 87<br>1231<br>1458 | METROMEX cloud base sampling - box around city | | |

Table 2. Con't.

| Date | TPS-10 films | Flight: No. T.O. Lndg | Flight Mission | CCN Bags Location | Ice Nuclei millipores |
|---|---|---|---|---|---|
| 14 Aug | 1230<br>1707 | | | | |
| 16 Aug | | 88<br>1341<br>1357 | Instrument malfunction - no data | | |
| 16 Aug | | 89<br>1617<br>1756 | Aerosol sampling | 1 upwind<br>1 downwind | 18 |
| 17 Aug | | 90<br>1748<br>1903 | Ice nuclei and state parameter METROMEX CROSS-SECTIONS | 1 upwind<br>1 downwind | 26 |
| 18 Aug | | 91<br>1638<br>1834 | METROMEX CROSS-SECTIONS over city 1.5 to 7.0 thousand stratocumulus replications | 1 downwind<br>5.5 thousand<br>1 downwind<br>1.5 thousand | 24 |
| 19 Aug | 1715<br>2124 | 92<br>1416<br>1552 | METROMEX Cloud Microphysics study. Fiber optics and replications of cumulus numerous locations over and near STL | 1 upwind<br>1 downwind | 24 |
| 20 Aug | 0945<br>1100;<br>1449<br>1803;<br>1842<br>1958. | | | | |

Table 2. Con't.

| Date | TPS-10 films | Flight: No. T.O. Lndg | Flight Mission | CCN Bags Location | Ice Nuclei millipores |
|---|---|---|---|---|---|
| 21 Aug | 1121<br>1818 | 93<br>1348<br>1626 | METROMEX CROSS-SECTION 245° from TOY. Flew CU Congestus, Cb 15-70 mi S of STL | 1 upwind<br>1 downwind | |
| 23 Aug | 1500<br>1715;<br>1844<br>1955 | 94<br>1251<br>1557 | METROMEX cloud microphysics haze content, heat island flight track MTS to 40 E MTS, CU penetrations. 20 N STL | 1 upwind<br>1 downwind | 34 |
| 23 Aug | | 95<br>1910<br>2011 | Calibration - runway speed run | | |
| 24 Aug | | 96<br>0521<br>1019 | Calibration speed run and METROMEX CROSS-SECTION. Track 10 NW STL - 30 SE STL. | 1 upwind<br>1 downwind | 64 |
| 24 Aug | | 97<br>1515<br>1537 | Fiber Optics test. | | |
| 24 Aug | | 98<br>1643<br>1808 | Fiber Optics test. | | |
| 25 Aug | 1319<br>1358;<br>1932<br>2103 | 99<br>1656<br>1721 | Calibration-speed run | | |
| 27 Aug | | 100<br>1248<br>1519 | METROMEX cloud microphysics. Flew box around St. Louis. Good state parameter, replicator, Fiber optics data. | 1 upwind<br>1 downwind | 28 |

Table 2. Con't.

| Date | TPS-10 films | Flight: No. T.O. Lndg | Flight Mission | CCN Bags Location | Ice Nuclei millipores |
|---|---|---|---|---|---|
| 28 Aug | | 101<br>1517<br>1801 | Fly-up to 16 thousand with 306 D. Equipment check. | 1 downwind<br>1 upwind | |
| 30 Aug | | 102<br>1304<br>1502 | METROMEX cloud microphysics Box around city. | 1 downwind<br>1 upwind | 21 |
| 31 Aug | | 103<br>1002<br>1308 | METROMEX CROSS-SECTION, box, and microphysics of alto-cumulus and cumulus. | 1 downwind<br>1 upwind | 21 |

# ILLINOIS STATE WATER SURVEY IN METROMEX

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## 1. Introduction

The Water Survey's plans and interests in METROMEX evolved from past principal research areas and available instrumentation. The principal investigators are Stanley A. Changnon, Jr., and Richard G. Semonin. The Water Survey's historical interest in precipitation studies, climatology, instrumentation (including dense surface meso-networks), inadvertent weather modification, and cloud physics (with specific reference to precipitation processes and rain scavenging) led to three major goals.

## 2. 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 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. 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.

## 3. Facilities

To obtain the measurements necessary to fulfill the three goals of the Water Survey required several extensive instrumental and observational tasks. These tasks included the installation and operation of 1) a large dense network consisting of 228 recording raingages and hailpads distributed evenly throughout the major research area of 2200 square miles (see Fig. 2 on page 8); 2) two radar systems located northwest of the major research area (see Fig. 2 on page 8); 3) "key stations" of various instruments including 3 that measured and recorded thunder, 2 that measured atmospheric electricity components; 3 that photographed clouds (time-lapse); 2 that recorded raindrop size spectra (spectrometers); and 4) a series of 7 surface stations that record temperature, humidity, and winds.

Other tasks involved 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 68 rainwater collectors (outlined on Fig. 4), and aircraft cross-sectional 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 (see Fig. 2 on page 8).

Funding has been received from the State of Illinois, Atomic Energy Commission, and the National Science Foundation. The Survey's measurements were made throughout the summer of 1971, although the aircraft operations were conducted from mid-July through August. Surface raingage and weather networks have been kept operational beyond August, and will be kept operational for the next 5 years.

## 4. Equipment Operational Catalogue - 1971

A daily record of operations and data availability is shown in Fig. 1. The availability of rainfall data from the 228 raingages in the research area is not indicated since these data are available in chart form throughout the 3-month period of the METROMEX project. The hailpads located in proximity to the recording raingages also provided hailfall data throughout the summer.

The FPS-18 radar remote scope was photographed on a nearly continuous basis from 21 June through 28 August, and these data also are not shown in Fig. 1. The data for the FPS-18 indicated in the figure are those in digitial form and on magnetic tape. The digital information was generated in a range-gated integrator over an area prescribed by the radar.

In Fig. 1 a solid line represents the continuous collection of data for the period indicated. A solid circle indicates specific event data within a 24-hour period, or in the case of the chemistry, it indicates the availability of analyzed samples. The asterisk indicates aircraft missions during which a tracer chemical was released in proximity to the sampling sub-network for rainwater chemistry.

Some specialized observational data which do not appear on Fig. 1, but which were obtained at the Pere Marquette Field Headquarters during the experimental period are: 1) standard weather station observations, including specials; 2) condensation nuclei observations (Gardner counter) obtained once each hour; and 3) ice nuclei concentration as determined by an NCAR counter.

There were 26 flights conducted over the research circle from 21 July through 27 August with an accumulated flight time of 48 hours. There were 5 flights (7/29, 8/3, 8/13, 8/14, 8/21) for the purpose of introducing tracer material into convective clouds and only one of these (8/13) was aborted. The remaining 21 flights were conducted to sample the nuclei, temperature, and moisture distributions over the metropolitan area. These missions were conducted along prescribed flight paths extending east-northeast to west-southwest and north-south with a crossover at the Arch in downtown St. Louis.

## 5. Preliminary Results - 1971

It is essential that the data collected be scrutinized, assimilated, and interpreted within a brief span of time following the project termination so that decisions concerning the next field operation can be intelligently obtained. Certainly much of the collected data of the Survey are amenable to routine analysis immediately following the observational period. The hail data obtained from the network of hailpads as well as much of the rainfall data fall into this category. Some of the chemical analyses of rainwater have been completed and likewise yield results, although preliminary, which are indicative of the success of the tracer release missions during the project.

With respect to the major goals of the Survey research the following results are apparent from our data for June-August 1971:

1) of 3 haildays observed in the research circle, 2 were from hailstorms that developed totally in the downwind area and the third had storms that maximized in the downwind region;
2) there was a west-to-.east increasing gradient in thunderstorm occurrence;
3) a distinct daytime heat island, as well as the expected nocturnal one, was observed from the surface network of hygrothermographs (note the 2-week mean patterns in the research circle on Fig. 2);
4) a plume derived from the surface heat island was detected aloft through aircraft measurements and frequently was observed to extend to cloud base levels;
5) partial analysis of individual rain cells in June and July indicates at least 3 preferred rain initiation sites, two of which are near industrial and/or power stations and the third is over the central city (an example of the rainfall pattern for the air mass showers on one day is shown in Fig. 3);
6) the total rainfall for the summer (June through August) maximized in the area which was hypothesized from the climatological data as the maximum (downwind) effect area (the June rainfall pattern in Fig. 3 reveals two highs which were prevalent in July and August); and
7) the release of tracer material into convective storms was observed to return in the rainfall within a time-distance relationship indicative of the possible rapid influence of industrial sources on the precipitation mechanism (an example of the concentration of lithium tracer released in the upper right corner of the network is shown in Fig. 4).

The above results are preparatory to the collation of additional measurements for the interpretation of the entire set of data acquired during the past summer. Although the summer of 1971 was abnormal (dry) in terms of total precipitation, it was generally successful for the goals of the project.

## 6. Operational Plans 1972

The initiation of the METROMEX field observational period in 1972 will be in the spring with the re-establishment of the full complement of raingages in the research circle. All of the equipment and data collection procedures outlined above for 1971 will be in operation on 1 June 1972 with few minor changes from the summer of 1971.

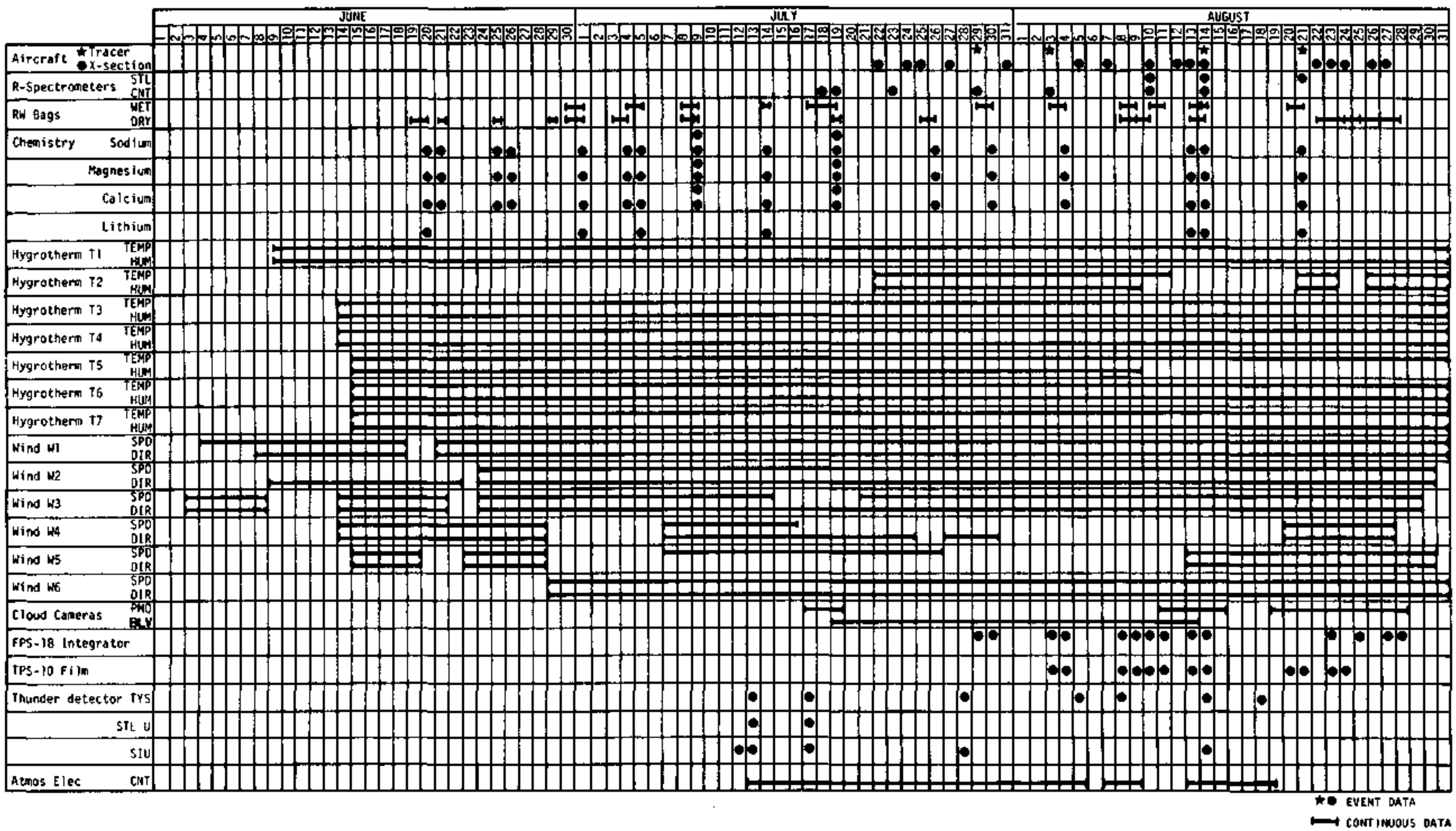


Figure 1. Water Survey Equipment Operation 1971.

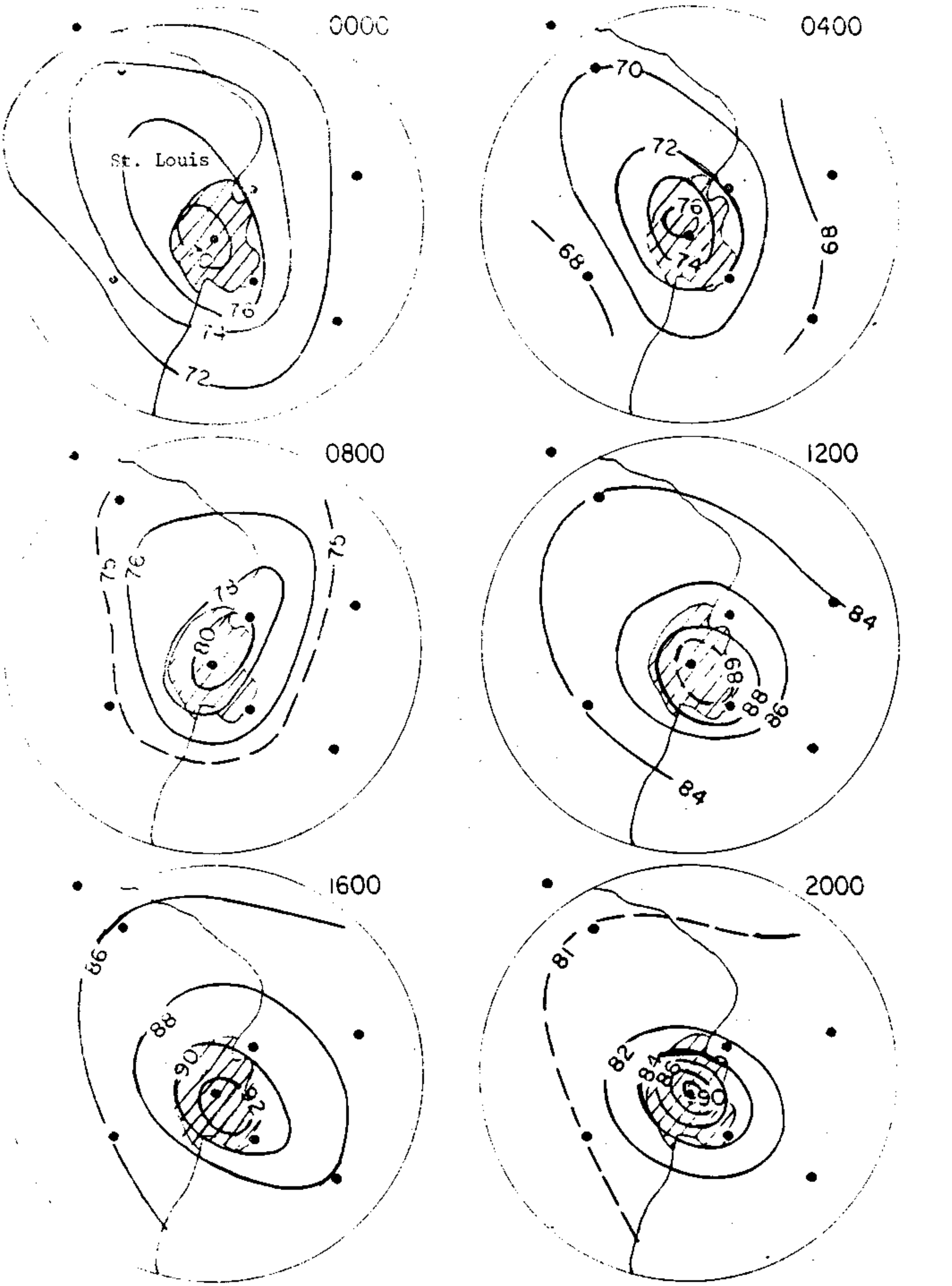


Fig. 2. Average June 16-30 temperatures, °F, at selected hours CDT,
Water Survey stations.

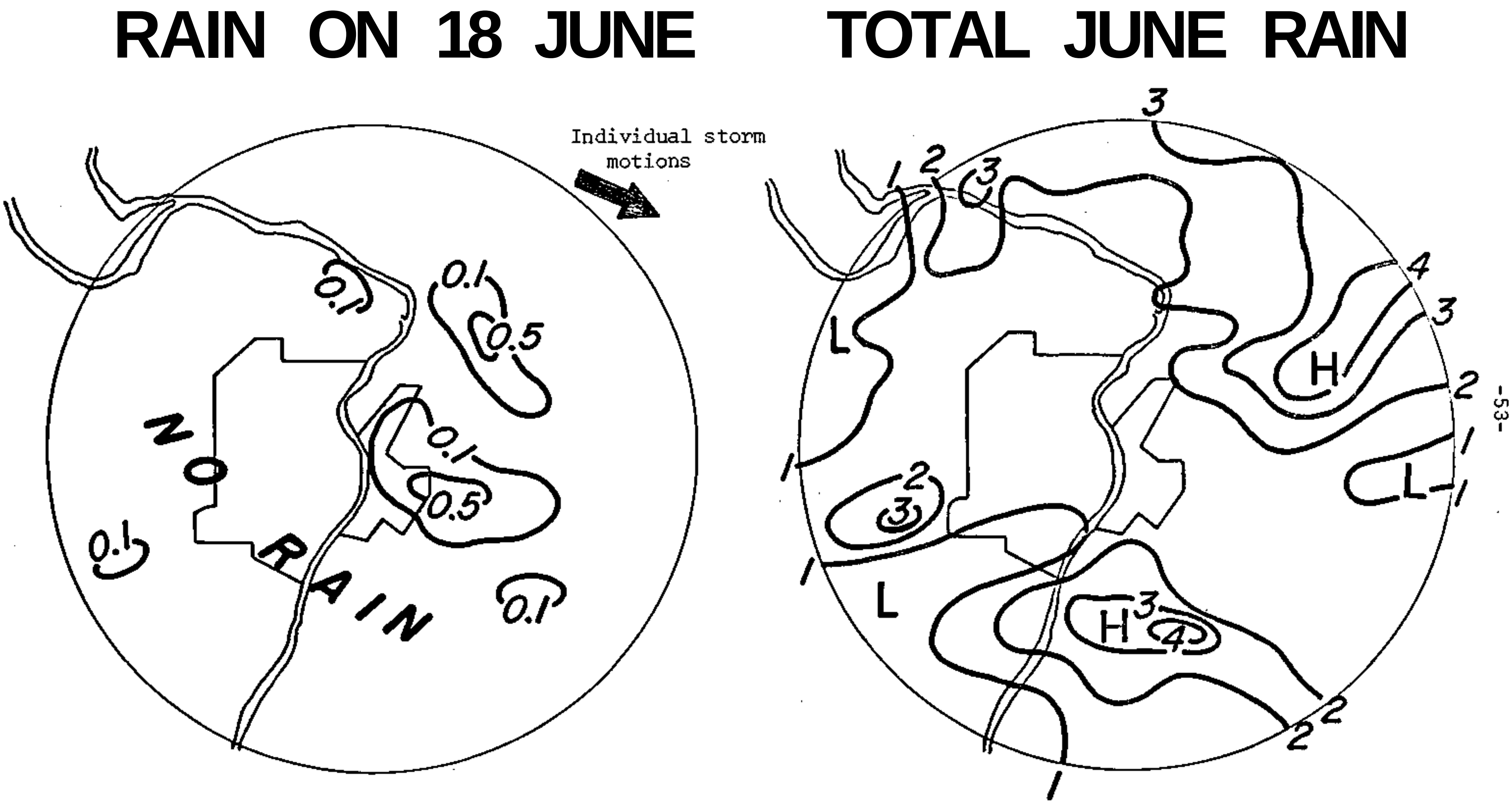


Fig. 3. Isohyetal patterns (in inches) for an air-mass shower day (18 June), and for the month of June 1971.

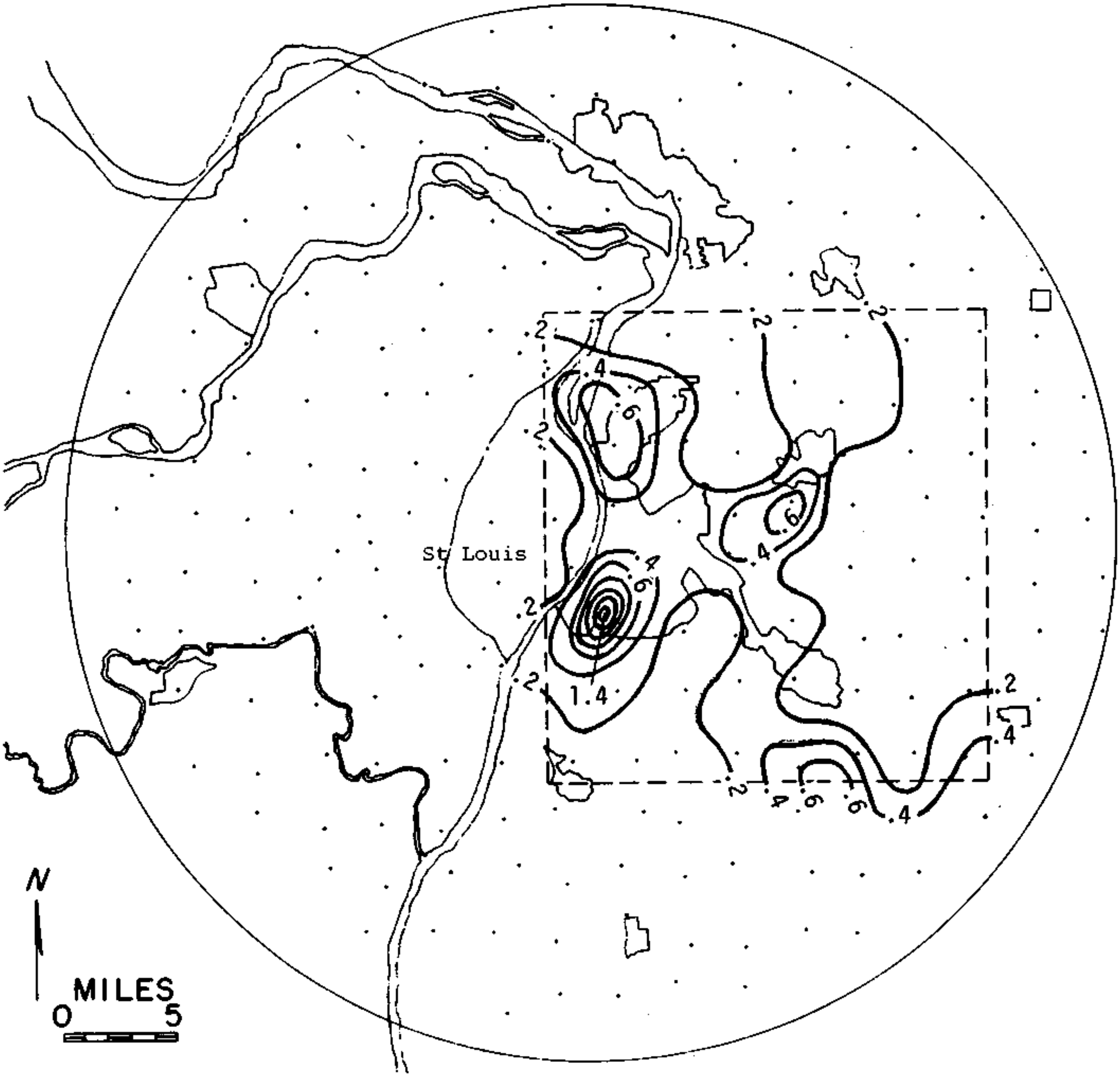


Fig. 4. Lithium concentration pattern in parts/billion for 14 August 1971.

Additional raindrop spectrometers will be installed in the research area to discern differences between storms which have ingested material from the urban complex and those in upwind control areas. These drop size data will have particular value to the scavenging studies when related to the airborne measurements of cloud particles by the Universities of Chicago and Wyoming.

The rainwater collection network will be enlarged and additional personnel will be assigned to the task of maintaining the network.

The aircraft operations will be similar to those undertaken during 1971, that is, to measure the vertical extent of the heat island and to sample the nuclei generated by the St. Louis complex. The aircraft will again be used as the platform for the low-level (cloud base) release of rare tracer chemicals into convective precipitation systems. These operations will be carried out during a 6-week interval beginning in mid-July.

Some minor improvements in the radar operations and data collection can be expected for the summer of 1972. These will include additional scopes of both the PPI and RHI to facilitate aircraft operations during storm situations and improved operational techniques for the recording of radar data on film and integrator tapes.

The weather teletype and facsimile data collected at the Field Headquarters will be available to those working in the field. Limited additional space at the Radar Operations Building will be available for personnel from the other cooperating groups for analysis of weather data unique to their missions.

# METROMEX, 1971: University of Wyoming Participation

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## Introduction

During the past decade there has been a very noticeable increase in pollution over and downwind of several large urban areas in the United States. Until recently, there was very little question except in certain special cases, that natural processes dominated the meso-scale weather systems. The effluent products from the large urban areas were quickly diluted by the surrounding unpolluted air, so that a few miles downwind from a pollution source little evidence of pollution could be detected. Today, however, attention should be given to the possibility that thermal pollution and microscopic particulates from urban-industry sources may in fact, be initiating and/or controlling the precipitation mechanism in a primary manner rather than being involved in a secondary process.

During the month of August, 1971, the Department of Atmospheric Resources, College of Engineering, University of Wyoming, initiated its first phase of the METROMEX field operation. The principal objectives of the University of Wyoming group during the 1971 METROMEX operations were:

A. Meso-scale circulation features
   (1) Observe and analyze the kinematics of the general meso-scale motion over an urbanized area and numerically model the meso-scale motions associated with an urban atmosphere; and
   (2) Make observations leading to the formulation of a relationship between the modification of air destined to enter thunderstorms from the horizontal flow of the subcloud region and the variations in the character of the cloud and its product.

B. Nucleus concentrations
   (1) Establish quantitatively the production of cloud, Aitken and ice nuclei by an urban environment.

C. Cloud and precipitation processes
   (1) Investigate the transfer process of the urban aerosol to the cloud particle;
   (2) Determine the effects of urban-produced cloud nuclei on the structure of the cloud;
   (3) Investigate the coalescence mechanism of precipitation associated with the polluted conditions; and
   (4) Investigate the evolution of resulting cloud particles into precipitation.

## Facilities

The Department of Atmospheric Resources has several major items of permanent equipment available for all research programs.

## Airborne Research Facilities

The Department currently operates a C-45H type aircraft which has been updated and has a useful load of about 3,200 lbs. The aircraft has been modernized utilizing Beechcraft Percheron kits in order to make it a much more effective tool. The aircraft is equipped with a L-band transponder, dual navigation and communications equipment, radar altimeter, ADF, ILS with glide slope, distance measuring equipment, IVSI rate of climb indicators, and a 3-axis auto-pilot with couplers.

The aircraft is also equipped with a digital data acquisition system, which is especially suited for airborne atmospheric research. The data system is a versatile, high resolution system which records analog and digital input data on one-half inch IBM computer-compatible magnetic tape.

The aircraft operational parameters recorded are heading, indicated airspeed, pressure altitude, manifold pressure, VOR azimuth and DME position, vertical acceleration, roll rate, pitch rate and rate of climb; meteorological parameters recorded are temperature, dew point, liquid water content, turbulence, flow through membrane filters, and time. The aircraft is also equipped with an onboard digital computer which makes possible the real time determination of ambient temperatures, potential temperatures, dew points, specific humidity, vertical velocities (updrafts), and time. The system is capable of telemetering data to the ground station if it becomes desirable.

The types of sensors employed within this system and their range, accuracy and resolution are given in Table 1.

The temperature and dew point transducers installed in the University of Wyoming aircraft were calibrated at the Jefferson County (Broomfield, Colorado) Airport by flying by the rotating beacon tower. Mr. Cleon Biter, National Hail Research Experiment (NCAR), analyzed these data and his results are presented in Table 2. In addition, a formation flight with the NCAR Buffalo aircraft was also conducted and the data from this comparison are being analyzed by Dr. Claude Duchon of Oklahoma State University.

Cloud physics measurements are taken at discrete points on the basis of decisions made by the scientist onboard the aircraft. Air samples from which cloud nuclei spectra are determined, are taken in aluminized mylar bags. A sequencing unit allows the simultaneous exposure of from 3 to 15 filters with solenoid-switched banks which allow rapid changeover of filter sets. A droplet replicating device is used for the determination of the size distribution of droplets in the size range of 5 to 30μ. This device uses soot-coated glass slides which are exposed to the airstream for a measured period of time. A single exposure foil impactor is used for the determination of concentrations of hydrometeors 250y or larger. Aitken nucleus concentrations are measured at desired times using a Gardner type-CN instrument.

## Mobile Sampling and Observing Units

Two carryall type trucks have been equipped for measurements of meteorological and precipitation parameters and to collect rapid-sequence air and precipitation samples for ice nucleation and chemical analyses.

Table 1. Instrumentation on the aircraft.

| Parameter Measured | Manufacturer and Model No. | Range | Accuracy Sensor / System | Resolution |
|---|---|---|---|---|
| Temperature | Rosemount Engr. Model 102 de-iced | -50C to +50C | ±1C / ±0.1C | 0.1C |
| Dew Point | Cambridge Systems Model 137-C3 | -50C to +50C | ±0.5C above 0C / ±1.0 below °C / ±0.1C | 0.1C |
| Heading | King Radio Model KP1550A | 360° | ±2° of local magnetic heading/1° | 1° |
| VOR Azimuth | King Radio Model KNR-660 | 360° | ±2° / ±1° | 1° |
| DME | King Radio Model KDM-700 | 0 to 99 nm | ±0.1 nm or ±0.2% of range Whichever is greater / +0.1 nm | 0.1 nm |
| Altitude | Ball Model 210B Total Pressure Transducer | 0 to 25 Kft | 0.05% / 0.1% | continuous |
| IAS | Rosemount Model 1301D Differential Pressure Transducer | 0 to 250 Kts | ±2 Kts / ±1 Kts | 1 Kts |
| Manifold Pressure | Computer Instruments | 15 to 30" Hg | 5% / ±0.1% | 0.1" Hg |
| Vane Angle or Angle of Attack | U.W. Atmospheric Research Group | 99° | 2% / 2% | 0.1° |
| Pitch Angle | Smith Industries Lmtd-Aviation Division Model 402RGS/-2 | 0 to ±20°/sec | 2% / 2% | 0.04° $sec^{-1}$ |
| Roll Angle | Smith Industries Lmtd-Aviation Division Model 402RGS/-2 | 0 to ±20°/sec | 2% / 2% | 0.04° $sec^{-1}$ |
| Vertical Acceleration | United Controls Model No. 2152 | ±3 g's | 1% of full range | 0.006 g's |
| Liquid Water | John Williams Model No. LWH | 0 to 3 gm $m^3$ | unk / ±0.1 g $m^{-3}$ | 0.1 g $m^{-3}$ |
| Turbulence | M.R.I. | | | |
| Ice Nuclei | Membrane Filters | | | |

Table 2. Results from Tower Comparison Flights.

Aircraft - Beech C-45, N600UW
Sensors - Temperature - Rosemount 102 (de-iced)
Dew Point Temperature - Cambridge Model 137-C3
Pressure - Ball Model 210B
8 June 1971

| Run | Time | IAS (Kts) | Temp. (°C) A/C | Temp. (°C) Tower | Temp. (°C) Diff. | $T_d$ (°C) A/C | $T_d$ (°C) Tower | $T_d$ (°C) Diff. | Press. (mbs) A/C | Press. (mbs) Bulova | Press. (mbs) Tower | Press. Diff. Bulova -Tower | Press. Diff. A/C -Tower | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0709 | 129 | 11.0 | 10.6 | +0.4 | 7.0 | 5.7 | +1.3 | 826.4 | 829.10 | 828.90 | +0.2 | -2.5 | Winds 300°/5-8 Kts. Clear sky. |
| 2 | 0715 | 124 | 10.9 | 10.7 | +0.2 | 7.5 | 5.75 | +1.75 | 826.9 | 829.10 | 828.90 | +0.2 | -2.0 | |
| 3 | 0726 | 124 | 10.8 | 10.6 | +0.2 | 8.5 | 6.8 | +1.5 | 827.3 | 829.10 | 828.90 | +0.4 | -1.4 | |
| 4 | 0732 | 124 | 10.9 | 10.6 | +0.3 | 8.7 | 7.0 | +1.7 | 827.3 | 829.00 | 828.70 | +0.3 | -1.4 | |
| 5 | 0737 | 123 | 11.1 | 10.7 | +0.4 | 8.7 | 7.35 | +1.35 | 827.7 | 829.10 | 828.70 | +0.4 | -1.0 | Winds 320°/5-8 Kts. |
| 6 | 0744 | 123 | 11.2 | 10.9 | +0.3 | 8.9 | 7.2 | +1.7 | 827.6 | 828.95 | 828.50 | +0.45 | -0.9 | |
| 7 | 0749 | 121 | 11.5 | 11.2 | +0.3 | 8.9 | 7.65 | +1.25 | 827.6 | 829.00 | 828.50 | +0.5 | -0.9 | |
| 8 | 0756 | 122 | 11.6 | 11.2 | +0.4 | 8.9 | 7.3 | +1.6 | 827.6 | 828.90 | 828.50 | +0.4 | -0.9 | |
| 9 | 0802 | 122 | 11.8 | 11.4 | +0.4 | 8.9 | 7.5 | +1.4 | 827.8 | 829.00 | 828.50 | +0.5 | -0.7 | |
| | | | Average: | | +0.3 | | | +1.59 | | | | +0.35 | -1.3 | |

Table 2. Results from Tower Comparison Flights (continued).

Aircraft - Beech C-45, N600UW
Sensors - Temperature - Rosemount 102 (de-iced)
Dew Point Temperature - Cambridge Model 137-C3
Pressure - Ball Model 210B
17 June 1971

| Run | Time | IAS (kts) | Temp. (°C) A/C | Temp. (°C) Tower | Temp. (°C) Diff. | $T_d$ (°C) A/C | $T_d$ (°C) Tower | $T_d$ (°C) Diff. | Press. (mbs) A/C | Press. (mbs) Bulova | Press. (mbs) Tower | Press. Diff Bulova -Tower | Press. Diff A/C -Tower | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0730 | 118 | 18.9 | 18.9 | 0.0 | 3.8 | 1.9 | +1.9 | | | | | | Winds light & variable. Sky, clear. |
| 6 | 0736 | 118 | 18.6 | 18.7 | -0.1 | 2.8 | 2.3 | +0.5 | | | | | | |
| 7 | 0741 | 117 | 18.8 | 18.5 | +0.3 | 2.7 | 1.4 | +1.3 | | | | | | |
| 8 | 0746 | 117 | 19.3 | 18.6 | +0.7 | 2.9 | 1.6 | +1.3 | | | | | | |
| 9 | 0751 | 119 | 19.4 | 18.6 | +0.8 | 2.7 | 1.1 | +1.6 | | | | | | |
| 10 | 0756 | 119 | 19.5 | 19.0 | +0.5 | 3.1 | 1.8 | +1.3 | | | | | | |
| 12 | 0807 | 116 | 20.2 | 19.4 | +0.8 | 4.2 | 2.4 | +1.8 | | | | | | |
| 13 | 08.12 | 116 | 20.5 | 19.7 | +0.8 | 4.4 | 3.1 | +1.3 | | | | | | |
| | | | Average: | | +0.5 | | | +1.4 | | | | | | |
| 2 | 1709 | 119 | 27.8 | 27.7 | +0.1 | +0.3 | -0.6 | +0.9 | | | | | | Thunderstorm just passed over the area but no rain has occurred in the vicinity. Winds are 15-20 kts. gusting to 25-30. Sky is overcast because of anvil shield. |
| 3 | 1715 | 118 | 27.8 | 27.5 | +0.3 | +0.2 | +0.4 | -0.2 | | | | | | |
| 4 | 1721 | 120 | 28.3 | 27.7 | +0.6 | -1.5 | -0.7 | -0.8 | | | | | | |
| 5 | 1727 | 119 | 28.5 | 28.0 | +0.5 | +0.1 | -0.8 | +0.9 | | | | | | |
| | | | Average: | | +0.4 | | | +0.2 | | | | | | |

The mobile units are equipped with a data recording system utilizing a 10 inch multipoint chart recorder.

Table 3 lists the instrumentation that has been installed in the mobile unit.

Measurements providing continuous signals are recorded with the aid of a multipoint chart recorder. This recorder provides a permanent record of each parameter with a repetition rate of 8 seconds per channel. The output of this recorder is immediately available for the operators so that changes and trends can be immediately observed.

Positioning and vectoring of the mobile unit is achieved with the aid of two-way FM radios which enable the operators to be in continuous contact with the METROMEX headquarters at Pere Marquette radar site and with the University of Wyoming aircraft crew during missions. Operations of the mobile units requires 3 attendants for maximum utilization of the system. In addition to making temperature and humidity transects across the Metropolitan area, the observers are also capable of taking pibal observations and making other relevant observations which are voice recorded. The observers also obtain photographs of significant phenomena.

Precipitation samples are collected in sterile plastic bags which are raised to a height of 20 feet above the ground during collections. Samples are frozen immediately after collection. Air samples are taken 18 feet above the ground; a sequencing unit allows exposure of 3 to 9 filters at any one time, with rapid switchover between sets of filters. Airflow rates are continuously recorded.

Other Facilities

A nucleus spectrometer is available for the determination of freezing nucleus concentrations in cloud water and in precipitation samples. Nucleus concentrations are derived over at least 3 orders of magnitude and up to 10 orders of magnitude can be covered by special methods. The range of temperatures investigated is 0°C to -25°C.

A processing unit for membrane filters is available for the determination of nucleus concentrations in air samples collected by either the aircraft or the mobile ground units. Improvements have been made on the design of earlier reported models of these devices such that temperature and supersaturations can be reliably controlled. The device is capable of simultaneously processing 16 filters.

A cloud condensation nucleus counter based on the thermal diffusion principle, was used for the determination of cloud nucleus spectra. This counter was designed and fabricated at the University of Wyoming and was improved considerably by the design of a better differential thermometer. This cloud nucleus counter was compared with other similar instruments at the International Instrumentation Workshop held in Lannemezan, France, in September, 1967. Results of this comparison suggested that the portable University of Wyoming cloud nucleus counter yields cloud nuclei concentrations remarkably compatible (correlation factor equal to 0.9) with the more sophisticated laboratory instruments at this workshop.

Table 3. Instrumentation on each mobile unit.

| Function | Device | Range | System Resolution | System Accuracy |
|---|---|---|---|---|
| Temperature* | Rosemount 104C platinum resistance sensor - ventilated | -50 to +50 | 0.1C | ±0.2C |
| Dew point* | Cambridge Systems Model 880 | -40 to +50C | 0.3C | ±2.0C |
| Wind speed* | RAIM No. 436 anemometer | 1-100 mph | 2 mph | ±5% |
| Wind direction* | RAIM No. 437 Vane | - | 16 point | - |
| Wind sounding | Single theodolite | - | - | - |
| Atmospheric Pressure | Belfort Model 355 R remote microbarograph | 650 to 1050 mb | 0.5 mb | Depends on reference |
| Air filter samples for IN measurements* | 3 x 3 sequential sampler with diff. pressure transducer | 20 lit $min^{-1}$ per filter | | ±5% of volume sampled |
| Rain drop-size distribution** | Rd-60 momentum sensor | 0.3>D>10 mm | 20 size groups | ±5% |
| Rate of Rainfall* | Stand-tube with discharge nozzle | $5<R<50$ mm $hr^{-1}$ steady, and $R \simeq 200$ mm $hr^{-1}$ transient | 3 mm $hr^{-1}$ | ±5 mm $hr^{-1}$ at high R |
| Rain and hail collection | 1) Replaceable bags 15 ft above ground<br>2) Hailstones quenched to dry-ice temp. | R>5 mm $hr^{-1}$ | - | - |

*Parameters recorded on multipoint strip chart recorder.
**Parameters recorded on analog magnetic tape.

The University of Wyoming Computer Center currently has one digital computer which is an XDS Sigma 7. The Department of Atmospheric Resources has the use of a remote batch terminal which is connected to the XDS Sigma 7.

All flight and mobile operations were conducted according to guidance weather forecasts provided by Wyoming personnel, using the complete teletype and map facsimile services provided by the Illinois State Water Survey at the Pere Marquette radar site.

## Calendar of Operations

The Department of Atmospheric Resources of the University of Wyoming participated in Project METROMEX during 2-27 August, 1971. A complete summary of operations involving Wyoming personnel and equipment is to be found in Table 4. In addition, this table provides a summary of collected data for ice and cloud nucleus concentrations.

Paramount in the University of Wyoming's airflow and modeling studies was the collection of temperature and humidity data at various altitudes, including levels less than 1,000 feet above the terrain to serve the needs of input and/or verification. Also, programs involving aerosol sampling dictated flights at low levels. In this regard, following the selection of a flight path over the Metropolitan area, letters were sent to some 27 local municipalities requesting permission to fly at altitudes less than 1,000 feet over their domain; with these letters in hand, an official filing of a waiver under Federal Aviations Regulations Part 91.63 was made to the Federal Aviation Administration and granted in early June, 1970. The issuance of this waiver allowed the University of Wyoming aircraft to fly at altitudes of 500 feet above ground level over the Metropolitan area.

Field operations relating to the investigation of modification of convective clouds by an urban area were severely hampered by an unseasonal drought during the month of August, 1971. This month was the second driest August on record and takes its place as the fifth driest month ever recorded at St. Louis, according to the National Weather Service records. Rainfall of only 0.08" was recorded at St. Louis Lambert International Airport, compared with an average rainfall of 3.02". For this reason, considerable more effort was put forward in the collection of airflow data during August, 1971, although some cumulus cloud physics data were obtained.

In addition to our own personnel and facilities, the University of Wyoming group also directed the operations of four double theodolite pibal teams provided by the U. S. Air Force, Air Weather Service. These teams launched pibals at 1 1/2 hour intervals over a six hour period from five sites which formed a quadrangle about 10 km in dimension around the major urban area. These launches were conducted on a routine basis beginning either at sunrise or mid-afternoon. Hourly weather observations were also made by the pibal teams.

Table 4. Project METROMEX Data Summary, August 1971.

| DATE | AIRCRAFT FLIGHT, CDT | PURPOSE OF FLIGHT[a] | MILLIPORE FILTERS TIME: ALTITUDE MSL[b] | CLOUD NUCLEI TIME & NATURE | AITKEN NUCLEI | UW PIBAL DATA TIME-LOCATION | USAF PIBAL DATA TIME - LOCATION[c] |
|---|---|---|---|---|---|---|---|
| 4 | --- | --- | 0700 Vent OFN (3) | --- --- | --- | --- --- | 0730 Arch<br>0900 Arch, 30<br>1130 Arch |
| 5 | 0655-0815 | TOY-PAC transect (2) | --- --- | --- --- | --- | 0555 Hamel<br>0620 Forest Park<br>0735 Forest Park<br>0905 Forest Park<br>0915 Forest Park<br>1100 Forest Park<br>1105 Hamel | 0600 Arch<br>0730 Arch<br>0900 Arch, 30<br>1130 Arch, 30 |
| 6 | --- | --- | 0820 PAC (1)<br>1030 Forest Park (2) | --- --- | --- | 0600 Hamel<br>0740 Forest Park<br>0900 Forest Park<br>1055 Forest Park<br>1100 Hamel | 0600 30<br>0626 16<br>0730 Arch, 6, 16, 30<br>0900 Arch, 6, 16, 30<br>1100 30<br>1130 Arch, 6, 16 |
| 7 | --- | --- | --- --- | --- --- | --- | --- --- | 0600 Arch, 30<br>0620 6<br>0625 16<br>0730 Arch, 16, 30<br>0740 6<br>0900 Arch, 6, 30 |
| 9 | 0635-0940 | TOY-PAC transect (2)<br>OFN-BLV transect (1) | 0800 PAC (2)<br>0820 2100 ft (1)<br>0850 1650 ft (1) | 0910 background<br>0930 polluted | whole flight | 0615 Hamel, Forest Park<br>0750 Forest Park<br>0900 Forest Park<br>1100 Forest Park<br>1145 Hamel | 0700 Arch<br>0900 Arch, 6<br>1130 Arch |
| | 1225-1435 | cumulus penetration | 1300E 5000 (1)<br>1355 1650 (1) | 1345 Cu base | whole flight | 1420 Olive & 141<br>1425 111 & U.S. 40<br>1435 Chesterfield | --- --- |
| 10 | 0600-0915 | TOY-PAC transect (4) | 0600 Hamel (1)<br>0730 Forest Park (4)<br>0835 PAC (1) | --- --- | whole flight | 0610 Hamel<br>0615 Hamel<br>0735 Forest Park<br>1100 Hamel | 0600 6, 16<br>0730 6, 16, 30<br>1100 6<br>1130 16 |
| 11 | --- | --- | --- --- | --- --- | --- | --- --- | 0600 16, 30<br>0730 6, 30<br>0740 16<br>0900 16, 30<br>1130 6, 16, 30 |
| 12 | 0610-0930 | TOY-PAC transect (4) | 0600 Hamel (1)<br>0645 6650 ft (1)<br>0730 Forest Park (4)<br>0740 1750 ft (1)<br>0758 PAC (1)<br>0806 1200 ft (1)<br>0905 5700 ft (1) | 0755 background<br>0810 polluted | whole flight | 0620 Forest Park<br>0735 Forest Park<br>0755 Forest Park<br>0900 Forest Park | 0600 Arch, 30<br>0615 6<br>0730 Arch, 6, 16<br>0900 Arch, 6, 16, 30<br>1130 Arch, 6, 16 |
| | 1030-1330 | OFN-BLV transect (2) | 1050 Hamel (1)<br>1155 3550 ft (1)<br>1245 1650 ft (1)<br>1305 Forest Park (4)<br>1330 OFN (1) | --- --- | whole flight | 1100 Hamel<br>1105 Forest Park<br>1300 Fort Zumwalt<br>1310 Forest Park<br>1350 Forest Park | --- --- |
| | 1505-1735 | OFN-BLV transect (2) | 1605 5500 ft (1)<br>1636 6700 ft (1)<br>1642 6700 ft (1)<br>1700 BLV (1)<br>1705 Forest Park (2) | --- --- | whole flight | 1515 Forest Park<br>1635 3 NE Freeburg<br>1640 Forest Park | --- --- |
| | 1845-2035 | TOY-PAC transect (2) | 1905 Forest Park (1)<br>1930 5600 ft (1)<br>2000 1750 ft (1)<br>2010 1750 ft (1) | --- --- | whole flight | 1835 Forest Park<br>1915 Hamel<br>2020 Forest Park | --- --- |
| 13 | 1430-1630 | Cumulus cloud study | 1515 Arch (2)<br>1540 1800 ft (1)<br>1615 7900 ft (1) | --- --- | --- | 1555 7N I-244 & Des Peres<br>1605 7N I-244 & Des Peres | 0600 6<br>0730 Arch, 6<br>0900 6, 30<br>1130 Arch, 6, 30 |
| 16 | --- | --- | --- --- | --- --- | --- | --- --- | 1530 6, 12, 16, 30<br>1700 12, 16, 30<br>1830 6, 30<br>2000 6, 12, 16 |

Table 4. (continued)

| DATE | AIRCRAFT FLIGHT, CDT | PURPOSE OF FLIGHT[a] | MILLIPORE FILTERS TIME: ALTITUDE MSL[b] | CLOUD NUCLEI TIME & NATURE | AITKEN NUCLEI | UW PIBAL DATA TIME-LOCATION | USAF PIBAL DATA TIME - LOCATION[c] |
|---|---|---|---|---|---|---|---|
| 17 | 1635-1800 | TOY-PAC transect (2) | 1655 1600 ft (1)<br>1710 1600 ft (1)<br>1735 1550 ft (1)<br>1755 1550 ft (1) | 1700 background<br>1715 polluted<br>1740 background | whole flight | --- --- | 1530 30<br>1600 16<br>1700 12, 16, 30<br>1830 6, 16, 30 |
| 18 | 1510-1735 | OFN-BLV transect (2) | 1605 7600 ft (1)<br>1625 7550 ft (1)<br>1645 1800 ft (1)<br>1700 1850 ft (1) | 1610 background<br>1700 polluted | whole flight | 1700 | 1530 6, 12, 16<br>1700 6, 12, 16, 30 |
| | 1830-2035 | OFN-BLV transect (2) | 1845 1700 ft (1)<br>1910 2000 ft (1)<br>1942 5550 ft (1) | --- --- | whole flight<br>whole flight | 1825 Arch<br>1835 Arch<br>2000 Fort Zumwalt | 1830 6, 12, 30<br>2000 6, 30 |
| 19 | 0700-1000 | OFN-BLV transect (2)<br>TOY-PAC transect (1) | 0715 Bamfort (1)<br>0715 6650 ft (1)<br>0750 1200 ft (1)<br>0805 1250 ft (1)<br>0830 2200 ft (1)<br>0840 Arch (2)<br>0845 2200 ft (1)<br>0920 6600 ft (1)<br>0935 6600 ft (1) | 0805 polluted<br>0935 background | whole flight | 0145 O'Fallon<br>0300 Arch<br>0720 Barnhart | 1530 6, 16, 30<br>1700 16, 30<br>1715 12<br>1830 6, 12, 16<br>2000 6, 12, 30 |
| 20 | --- | --- | --- --- | --- --- | --- | --- --- | 1530 6, 12, 16, 30<br>1700 6, 12, 16, 30<br>1800 12<br>1830 6, 30<br>2000 6, 12 |
| 23 | 1130-1450 | Cumulus cloud study | 1205 1650 ft (1)<br>1220 1650 ft (1)<br>1245 2000 ft (1)<br>1310 4700 ft (1)<br>1416E 7000 ft (1)<br>1428 5600 ft (1) | 1425 polluted Cu<br>1446 background Cu | whole flight | 1335 MTS VOR | 0600 30<br>0730 6, 30<br>0900 6, 12, 30<br>1030 30 |
| | 1630-1905 | Cumulus cloud study | 1650 ascent (1)<br>1730E 7000 ft (1) | 1745 Cu[+] | whole flight | --- --- | --- --- |
| 24 | --- | --- | --- --- | --- --- | --- | --- --- | 0600 6<br>0730 6, 12, 30<br>0900 6, 12<br>0930 30<br>1030 6, 12, 16, 30 |
| 25 | --- | --- | --- --- | --- --- | --- | 0100 MTS VOR<br>0250 2 S Winfield | 0600 12, 30<br>0615 6<br>0730 6, 12, 30<br>0900 6, 12, 30<br>1030 6, 12, 30 |
| 26 | 0610-0925 | OFN-BLV transect (4) | 0625 1900 ft (1)<br>0655 1900 ft (1)<br>0710 2000± ft (1)<br>0720 1300 ft (1)<br>0755 7100 ft (1)<br>? 3300 ft (1) | 0725 polluted<br>0740 polluted<br>0920 background | whole flight | --- --- | 0600 16, 30<br>0630 6<br>0730 12, 30<br>0900 6, 12, 16, 30<br>1030 6, 12, 30 |
| 27 | 0715-0905 | OFN-BLV transect (2) | 0740 1700 ft (1)<br>0745 1700 ft (1)<br>0805 1400 ft (1)<br>0815 1200 ft (1) | 0820 polluted<br>0830 polluted<br>0855 background | whole flight | --- --- | 0600 16<br>0615 6<br>0630 30<br>0730 12, 30<br>0745 16<br>0900 12, 16, 30<br>1030 6, 12, 16 |
| 28 | --- | --- | --- --- | --- --- | --- | --- --- | 0600 16, 30<br>0730 12, 30<br>0900 16, 30<br>1030 6, 12, 16,30 |

(a) The number in parentheses following the word "transect" in the Purpose of Flight column refers to the number of transects flown.

(b) The number in parentheses following the location or altitude in the Millipore Filter column refers to the number of groups of exposed millipore filters (3 filters per group). The filters used were Millipore type HA cellulose ester membranes having a mean pore size of 0.45 microns.

(c) The number in the USAF Pibai Data column refer to the site locations as designated by B. Ackerman. All USAF pibal data was made with the double theodolite system, while all UW pibal data was collected with single theodolite systems.

## Preliminary Findings

### Condensation Nuclei

Concentrations of cloud nuclei at activating supersaturations from 0.2% to 3.5% were measured with a thermal diffusion chamber. Air samples, collected in metalized mylar bags, were gathered by the aircraft at various locations, both upwind and downwind from the Metropolitan area. The samples were processed in the thermal diffusion chamber and corrections were made for the diffusion of nuclei to the walls of the bags. Aitken nuclei concentrations were also measured along the flight path using a Gardner small particle counter (type CN); measurements of Aitken nuclei were obtained simultaneously with the acquisition of cloud nucleus samples. Additional Aitken nuclei measurements were also made at more frequent intervals, especially during airborne transects across the Metropolitan area.

Figure 1 shows the results of the cloud nucleus observations taken upwind and downwind of the greater St. Louis area. Both the range of the individual cloud nucleus spectra as well as the average values are shown in Figure 1. It should be noted in Figure 1 that the cloud nucleus spectra have been extended to include the concentrations of Aitken nuclei; estimates of the activating supersaturations within the Gardner counter can be reasonably made with procedures developed at the University of Wyoming.

In general, it can be seen from Figure 1 that the background cloud nucleus population of upwind air activated at 0.2% supersaturation is changed very little by passage over the Metropolitan areas; however, at activating supersaturations near 1%, the cloud nucleus popultaion is increased by 100%. On the average, Aitken nuclei concentrations are increased downwind of the Metropolitan area by an order of magnitude above the upwind values.

### Modeling Studies

A modified form of the Lavoie (1968) airflow model has been prepared for study of the airflow over the St. Louis urban area. This model is hydrostatic and treats the air as being incompressible. The model assumes a well-mixed layer in the lower troposphere capped by a temperature inversion and stable layer. Divergence, horizontal velocity and vertical displacement of the airflow are computed within the well-mixed layer. The airflow in this layer is altered in response to forcing from the friction layer due to variations in terrain height, frictional drag and low-level heating.

A 39 x 39 grid has been constructed for the St. Louis area using a 2 km grid interval which expands geometrically near the boundaries. This grid expansion extends the outer boundaries well beyond the urban area (approximately 100 km) and also provides a damping mechanism for the elimination of certain spurious disturbances resulting from the numerical method.

Each of the three forcing mechanisms has been evaluated at each grid point. Terrain heights were determined directly from contour maps. Variations in the boundary layer stress were parameterized into the model by the bulk aerodynamic method using a drag coefficient formulation. The drag coefficient is evaluated at each grid point on the basis of roughness elements characterized by the area which the grid point represents. Eight categories

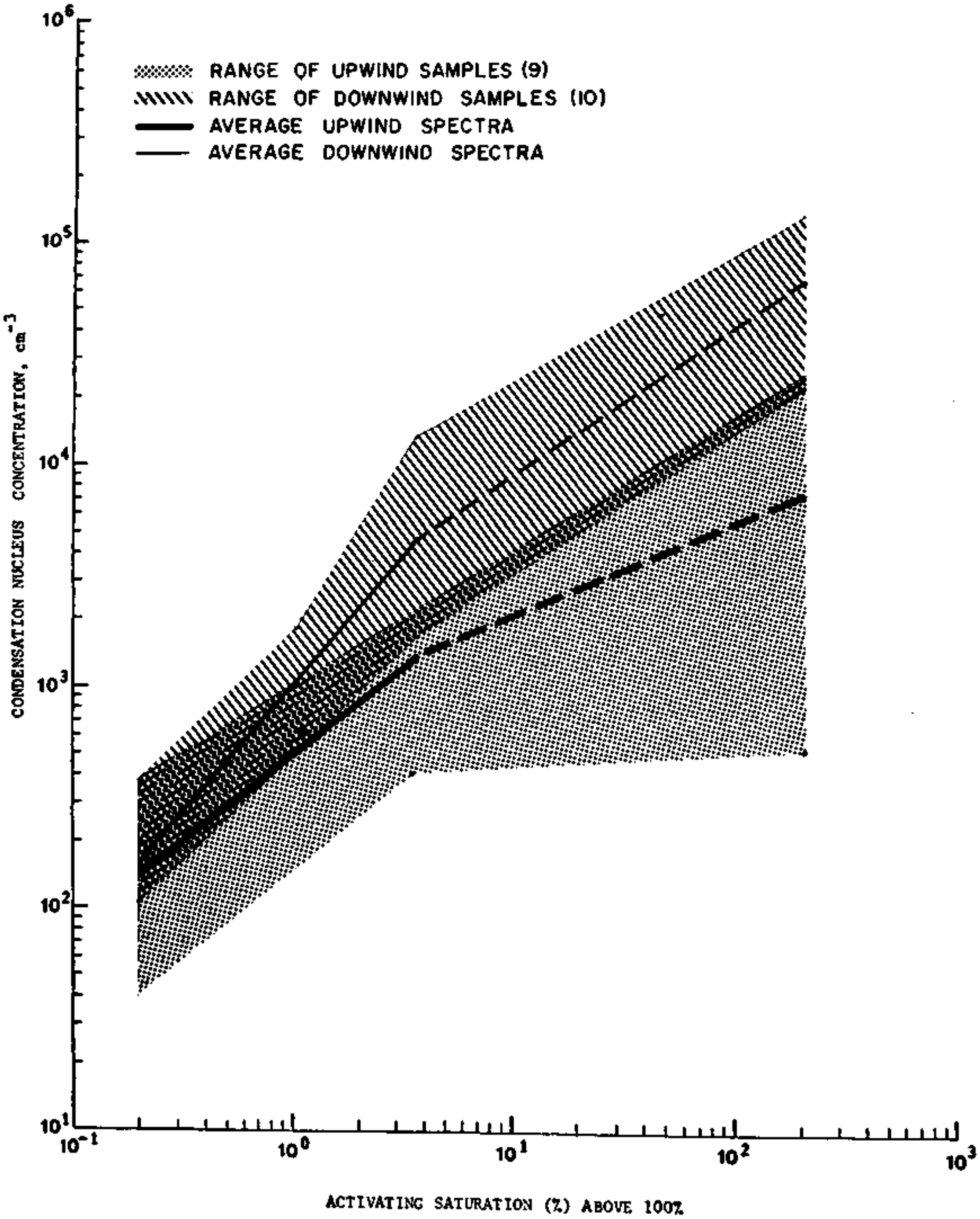


Figure 1. Condensation nucleus spectra observed in Project METROMEX during August 1971.

of roughness elements were defined on the basis of land use and building size and density. A roughness length was then estimated for each category on the basis of an empirical formulation proposed by Lettau (1969). An idealized urban temperature field was constructed on the basis of preliminary low-level aircraft flights across St. Louis plus a general synthesis of previous heat island measurements.

The extent of the non-expanding portion of the grid is shown in Figure 2. The terrain contours and prominent features in the St. Louis urban area are also shown. The heavily shaded box represents a. region of maximum surface heating in the model while the lightly shaded box represents an area in which the magnitude of the urban temperature excess decreases linearly to zero. Initially a value of 4°C was chosen as the maximum value of the urban temperature excess in the model. These values were found to be consistent with the measurements obtained from surface transects made during August, 1971.

Preliminary modeling studies were performed using typical vertical profiles of wind and temperature during convective days in the St. Louis area. The purpose of these studies was to evaluate the relative importance of each of the forcing components in producing the total perturbation field of airflow in the urban area. Figures 3, 4, and 5 represent results of some of the studies using a well-mixed layer extending to 1,200 meters (agl) and winds from 135° at 10 mps. The analysis in these figures correspond in scale and area to the map shown in Figure 2. The combined effects of all of the forcing influences are shown in Figure 3 producing a lowering of the top of the well-mixed layer by 60-80 meters immediately upwind of the city while the inversion level is lifted up to 180 meters immediately downwind of the downtown area.

The dominant terrain features seen in Figure 2 are the low flat bottom area east of the Mississippi River and a prominent hill southwest of the urban area. The effects of the terrain alone on the airflow are shown in Figure 4. It appears that most of the lowering of the inversion level upwind of the city is accounted for by the wide river valley in this region. It may also be noted that the prominent hill southwest of the city does not produce a significant perturbation on the airflow. (In cases of southwesterly flow the influence of this hill is more noticeable but still quite limited in its areal extent.)

The contributions of the heating and friction components over a flat terrain are shown in Figure 5. It is clearly seen that most of the lifting of the inversion downwind of the city is produced by these components. In addition, these components have the effect of lowering the inversion significantly (80 meters) in a region northeast of the city. To further distinguish between these two components other cases were run incorporating the friction effect alone. In this case the inversion level was only slightly altered (on the order of 20 meters) and it appears that the variation in roughness does not contribute significantly to the perturbations of the airflow. It must, however, be pointed out that the variable drag coefficients also influence the turbulent transfer of heat into the atmosphere so that in regions where the drag coefficient is large, the vertical mixing of the urban heat island is also increased.

These theoretical studies suggest that the presence of an urban heat island of a magnitude of only 4°C is sufficient to largely dominate the

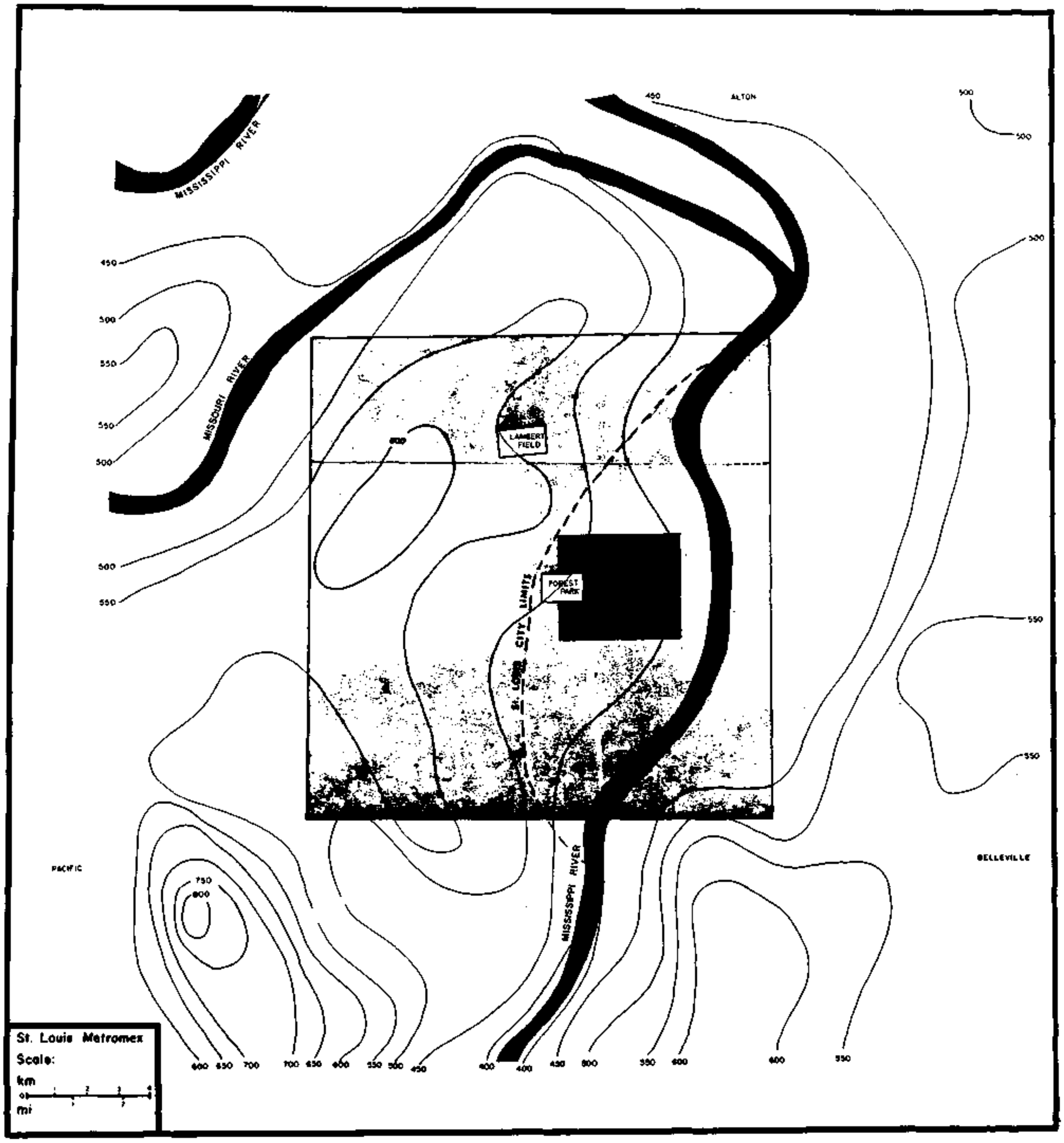


Figure 2. Terrain map of St. Louis with contours in ft above sea level. The light etched area being the area of partial heating and darkest area the area of maximum heating.

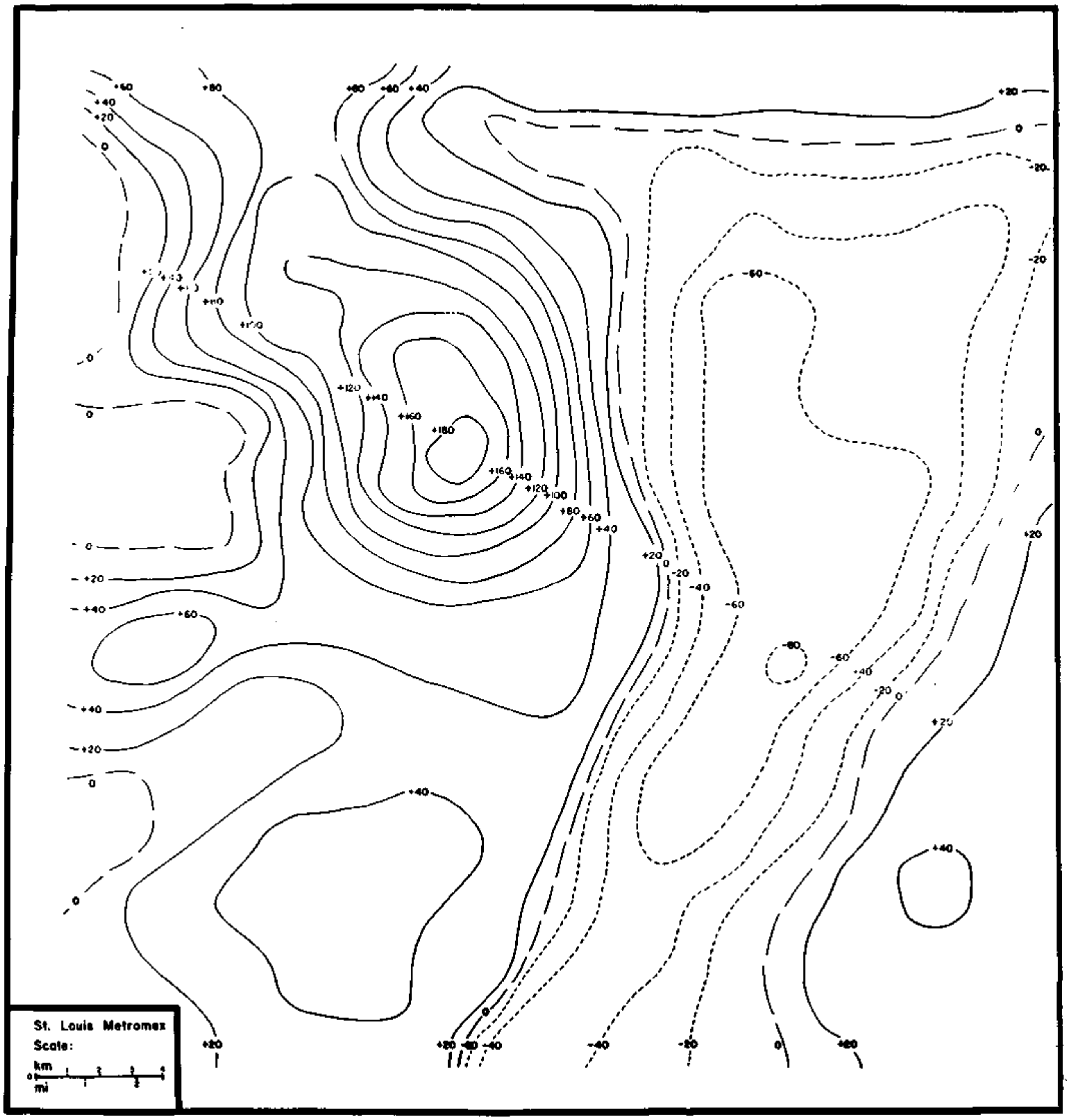


Figure 3. Model results after 3600 seconds with terrain, friction and heating present. Solid lines indicate inversion lifting in meters and dashed lines indicate inversion subsidence in meters.

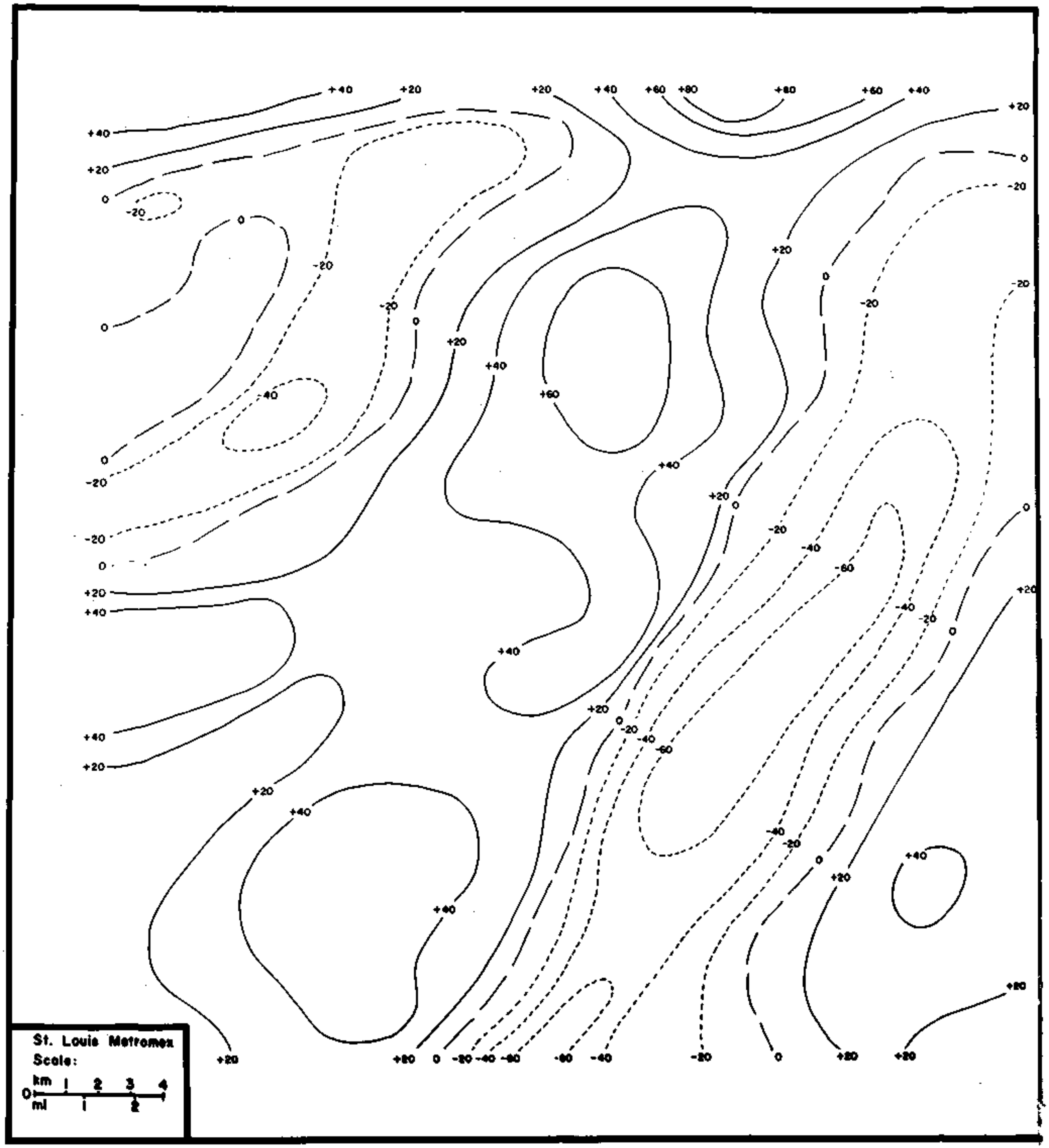


Figure 4. Model results after 3600 seconds (120 time steps) with terrain height influences only. Solid lines indicate inversion lifting in meters and dashed lines indicate inversion subsidence in meters.

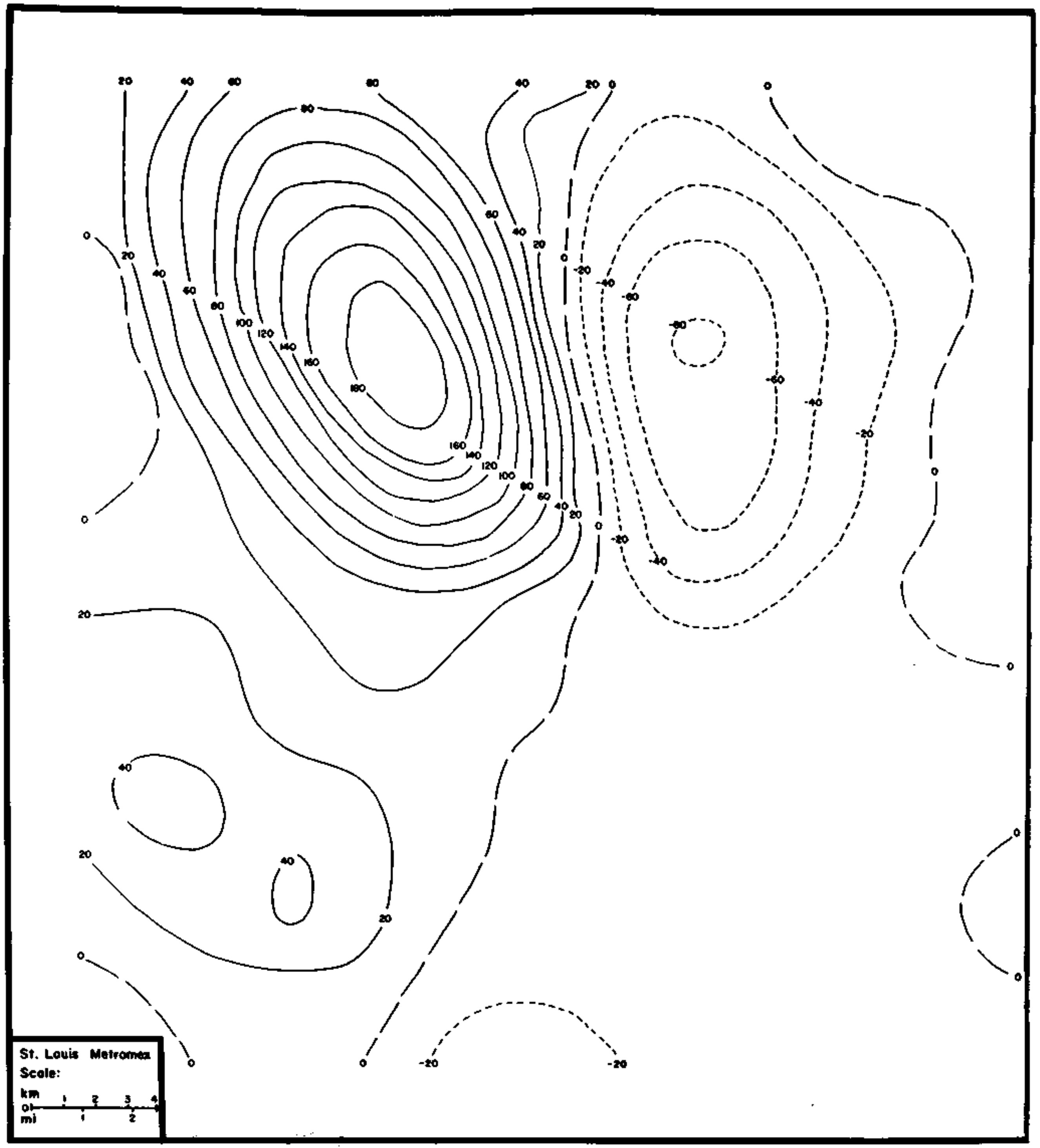


Figure 5. Model results after 3600 seconds (120 time steps) with heating and friction present. Solid lines indicate inversion lifting in meters and dashed lines indicate inversion subsidence in meters.

perturbed state of the urban airflow in the St. Louis area. Terrain effects are only secondary and effects due to variations in frictional drag are essentially negligible. Furthermore, the magnitude of the disturbance produced by the "urban island" is sufficiently large, on the order of 150-200 meters, that it should be detectable from aircraft flights and is of such a magnitude that it could significantly influence convective activity.

A preliminary analysis of some of the data recorded from the aircraft flights and from the surface mobile weather stations suggests several features related to the effect of the St. Louis urban area on the structure of the atmosphere. Nighttime and early morning surface transects reveal an urban temperature excess on the order of 3-5°C. Even during the daytime temperature excesses of 1-2°C were measured. Definite temperature anomalies were noted in such large areas as Forest Park. Low-level aircraft flights (500-1,000 feet agl) indicate that the "heat island" at this level does not exceed 1 or 2°C. Surface moisture data have not been adequately analyzed to distinguish any preliminary results. However, several aircraft flights at low levels suggest that there is a reduction of moisture (specific humidity) over the urban area. These particular flights occurred on days when pollution levels were high and it is possible that the reduced moisture content in the atmosphere is due to water vapor absorption by the haze particulates.

The vertical profiles of temperature over the city generally show adiabatic layers separated by well-defined inversions. Aircraft flights in the vicinity of these inversion levels indicate that short wavelength oscillations occur frequently along these discontinuities. It is interesting that such oscillations are particularly prevalent in the rugged terrain regions in the vicinity of Pacific, Missouri. There is also a suggestion from data taken in the late morning on a heavy pollution day that the upper regions of the pollution layer may be significantly heated. Thus, solar radiation is causing instabilities and convective overturning within this upper region (6,000 - 8,000 feet msl).

Atmospheric conditions are generally found to be non-steady, even during the time of a series of aircraft flights, on the basis of sequential aircraft soundings made upwind and downwind of the urban area. These complexities combined with the variations due to non-adiabatic influences make a simple interpretation of the data questionable. The general picture of the urban airflow and atmospheric structure, however, is encouraging and suggests that the "urban island" produces a significant dynamic influence on the atmosphere which is a plausible mechanism for the enhancement of convective activity and convective precipitation downwind of the urban area.

Reduction of the pibal data for the month of August, 1971, has been completed. The reduced data have been treated by a computerized smoothing technique which minimizes slope discontinuities in the wind field and balloon rise rate data. Both smoothed and unsmoothed data are being evaluated. Preliminary indications are that the mean airflow perturbations produced by the "urban island" are of sufficient magnitude to be reliably determined by these data.

## Plans for August, 1972

The research goals and operational plans for August, 1972, will essentially be the same as those for 1971. It is hoped that more emphasis can be placed on cloud physics observations because of the dearth of such observations in 1971. Objectives of the airflow study will be undertaken on more of a "case study" basis in an attempt to isolate some of the dominate urban airflow features.

## Acknowledgments

This research was made possible by the Department of Health, Education and Welfare, Environmental Protection Agency, Grant AP01174-02 to the Department of Atmospheric Resources, College of Engineering, University of Wyoming.

## References

Lavoie, R. L., 1968: A meso-scale numerical model and lake-effect storms. Ph.D. Dissertation, Department of Meteorology, Pennsylvania State University, University Park, Pennsylvania, 102 pp.

Lettau, H., 1969: Note on aerodynamic roughness-parameter estimation on the basis of roughness-element description. J. Appl. Meteor., 8, 828-832.

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Telephone (S09) 946-2121
or 942-1111
Telex 36921

September 15, 1971

Memo to: Metromex Colleagues

From: Ned A. Wogman

Attached are preliminary data logs of the sampling times for air particulates and the times of various chemical burns at ground level. All samples listed—as well as all rain samples collected between 8-3-71 and 8-19-71—will be analyzed for their trace element contents. Data should be available for comparative purposes in six months.

We wish to thank all Metromex personnel who assisted our operation and will appreciate receiving data summaries from the investigators as they can make them available.

Sincerely,

Ned A. Wogman

cc: A. Auer
B. Ackerman
D. Bailey
R. Braham
S. Changnon
F. Eden
D. Gatz
R. Semonin
E. Uthie
P. Wyckoff

# DATA SUMMARIES

# OF

# ALLIED GROUPS

## METROMEX

Battelle-Northwest

### Miscellaneous Notes

1. Lundgren and Anderson impactor particle size air samples were obtained on 8-14-71 to 8-16-71, 8-16-71 to 8-18-71, and 8-18-71 to 8-19-71.

2. Hurricane air samplers were utilized to sample air on a daily basis from 8-3-71 to 8-19-71.

3. Anderson particle size samples were obtained on the 8-10 to 8-11-71 burn of the Ru, Au, and Se.

METROMEX

Battelle-Northwest

Aircraft Air Sampling

| Date | Zulu Time | Altitude (ft.) | Relative St. Louis Position |
|---|---|---|---|
| 8-3-71 | 1757 | 15,000 | Upwind |
| | 1828 | 12,000 | " |
| | 1850 | 9,000 | " |
| | 1911 | 6,000 | " |
| | 1932 | 3,000 | " |
| | 2030 | 15,000 | Downwind |
| | 2049 | 12,000 | " |
| | 2119 | 9,000 | " |
| | 2135 | 6,000 | " |
| 8-4-71 | 1521 | 3,000 | Downwind |
| | 1537 | 5,000 | " |
| | 1554 | 10,000 | " |
| | 1612 | 12,000 | " |
| | 1628 | 15,000 | " |
| | 1700 | 20,000 | " |
| | 1750 | 20,000 | Upwind |
| | 1832 | 15,000 | " |
| | 1903 | 12,000 | " |
| | 1924 | 9,000 | " |
| | 1945 | 6,000 | " |
| | 2008 | 3,000 | " |
| 8-10-71 | 1755 | 15,000 | Upwind |
| | 1827 | 12,000 | " |
| | 1849 | 9,000 | " |
| | 1910 | 6,000 | " |
| | 1933 | 3,000 | " |
| | 2021 | 15,000 | Downwind |
| | 2039 | 12,000 | " |
| | 2058 | 9,000 | " |
| | 2115 | 6,000 | " |
| | 2133 | 3,000 | " |

| Date | Zulu Time | Altitude (ft.) | Relative St. Louis Position |
|---|---|---|---|
| 8-11-71 | 1438 | 15,000 | Upwind |
| | 1511 | 12,000 | " |
| | 1533 | 9,000 | " |
| | 1555 | 6,000 | " |
| | 1618 | 3,000 | " |
| | 1708 | 15,000 | Downwind |
| | 1725 | 12,000 | " |
| | 1743 | 9,000 | " |
| | 1800 | 6,000 | " |
| | 1817 | 3,000 | " |
| 8-17-71 | 1718 | 15,000 | Upwind |
| | 1750 | 11,000 | " |
| | 1811 | 9,000 | " |
| | 1832 | 5,000 | " |
| | 1853 | 3,000 | " |
| | 1938 | 15,000 | Downwind |
| | 1954 | 11,000 | " |
| | 2011 | 9,000 | " |
| | 2027 | 5,000 | " |
| 8-18-71 | 1531 | 20,000 | Upwind |
| | 1613 | 15,000 | " |
| | 1645 | 12,000 | " |
| | 1707 | 9,000 | " |
| | 1730 | 7,000 | " |
| | 1752 | 3,000 | " |
| | 1834 | 20,000 | Downwind |
| | 1909 | 15,000 | " |
| | 1941 | 12,000 | " |
| | 2000 | 9,000 | " |
| | 2017 | 7,000 | " |
| | 2035 | 2,100 | " |

METROMEX

Battelle-Northwest

**Tracer Release**

| Date | Local Time | |
|---|---|---|
| 8-10-71 | 2352 | Started burn of Ruthenium |
| 8-11-71 | 0004 | Finished burn of Ruthenium |
| | 0008 | Started burn of Gold |
| | 0018 | Finished burn of Gold |
| | 0025 | Started burn of Selenium |
| | 0035 | Finished burn of Selenium |
| 8-14-71 | 1302 | Started burn of Ruthenium |
| | 1315 | Finished burn of Ruthenium |
| | 2058 | Started burn of Gold |
| | 2134 | Finished burn of Gold |

UNIVERSITY OF CALIFORNIA, SAN DIEGO

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VISIBILITY LABORATORY
SCRIPPS INSTITUTION OF OCEANOGRAPHY

SAN DIEGO, CALIFORNIA 92152

8 October 1971

Illinois State Water Survey
Post Office Box 232
Urbana, Illinois 61801

ATTENTION: Mr. Richard G. Semonin
METROMEX

Dear Dick:

Please extend my apologies to Stan. I let his September request get away from me during our preparations for this month's flight program here on the West Coast.

We were delighted to be operating in the St. Louis area during the interval covered by the METROMEX program. We are looking forward to a pleasant and fruitful exchange of data with several of the many scientific teams who were in operation under Stan's able coordination.

I am enclosing for your information and further distribution, selected portions of our Atmospheric Visibility Technical Note No. 35. This in-house Note contains a description of our technical procedures and summarizes the data collected. I hope these enclosures are sufficiently detailed for your requirements. If not, give me a call and I'll supplement them as necessary.

Unfortunately, we were not in the air on 21 August 1971. However, I think the case study idea is a fine one. Our data processing is running on back log at the present time, so the August data is only getting validation checks. In the event some specific flight data becomes of particular interest, I can have it processed out of sequence on rather short notice, so let me know if it would help.

Best regards,

Richard W. Johnson
Project Engineer

RWJ:sam

cc: OPA/Dr. R. W. Fenn/4344
S. Q. Duntley
J. I. Gordon

Enclosures

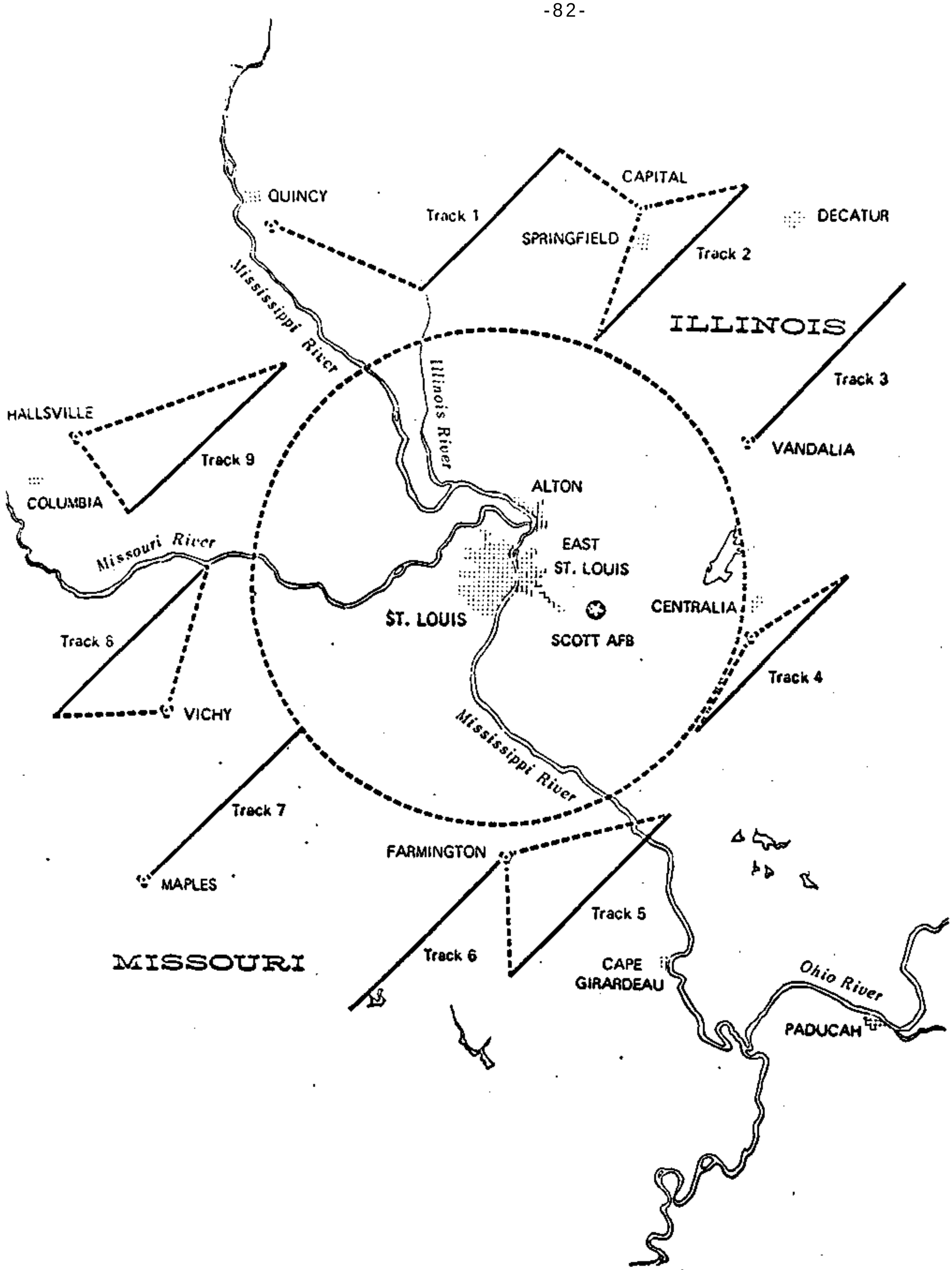


Fig. 1. Typical METRO Flight Tracks.

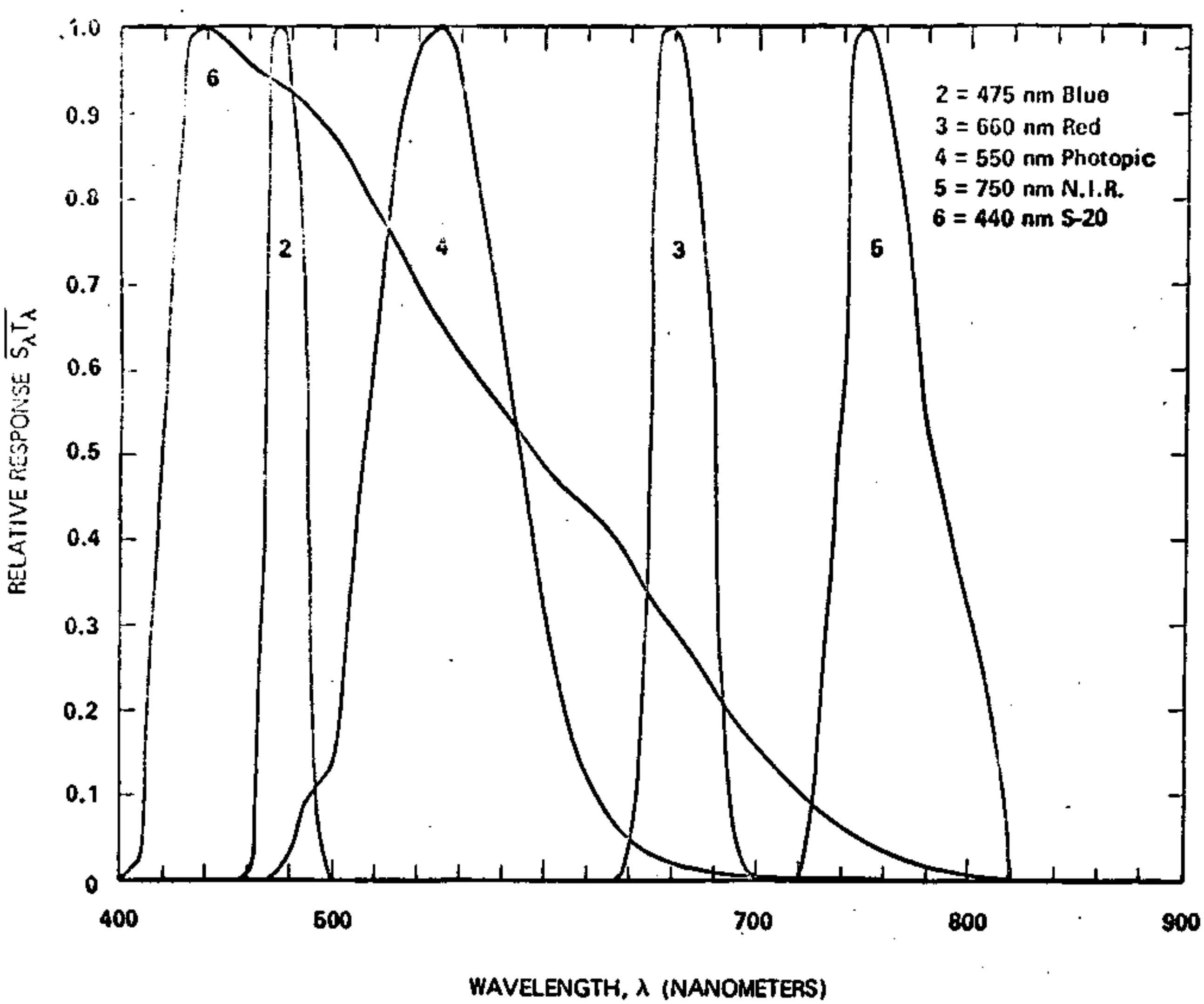


Fig. 3. Standard Spectral Responses - Project METRO.

SUMMARY OF AVAILABLE DATA

During the 15-day Project METRO deployment, there were nine successful data collection flights, and seven successfully completed ground-based data collection sequences. Tables 5 and 6 summarize the complete data bank acquired during this deployment. The processing of this data is currently underway at the Visibility Laboratory. Technical Notes covering each data flight in detail will be issued as the data completes its initial processing and evaluation.

Descriptive notes pertaining to the general atmospheric conditions during each data collection flight.are listed in the following paragraphs.

- Flight Descriptions -

Flight C-180, Track 1

Moderate haze, with not more than 0.2 scattered clouds.

2055z; Cloud bases at approximately 5500 ft.
2059z: Below top of haze layer at 5500 ft.
2147z: On top at 9500 ft. moderate haze below and scattered cumulus on the horizons.
2211z: Clear overhead at 17,500 ft.

Flight C-181-1, Track 3

Moderate haze, with haze top about 5500 ft., no clouds estimated 10 mile slant range visibility.

Flight C-182-1, Track 7

Moderate to heavy haze.

1510z: Light to moderate haze, no clouds overhead.
1535z: Clear above with scattered cumulus below at 5500 ft.
1553z: Moderate to heavy haze at 8500 **ft.**
1604z: Scattered cumulus below, light smoke from wood kiln.

Flight C-182-2, Track 3

Moderate to heavy haze, heavy haze layer at about 6000 ft. Haze appears heavier on Track 3 than on Track 7.

1718z: Heavy haze, no clouds above.
1738z: Moderate to heavy haze at 5500 ft.
1755z: Estimated 10 mile slant range visibility.
18lAz: Estimate top of haze at 10,500 ft.
1831z: Very hazy at 9500 ft.

Flight C-183-1, Track 7

Moderate to heavy haze, no clouds overhead.

1510z: Entering smoky area, sharply reduced visibility.
1529z: hazy at south end of track.
1540z: On top edge of haze at 9500 ft., basic layer appears to be about 7500 ft., thinning with new layer from 9500 to 10,500 ft.
1633z: Large cloud buildup below and to the east during Filter 4 climb to 7500 ft.

Flight C-183-2, Track 4

Heavy haze, slightly broken up above.

1727z: Bumpy ride at low altitude.
1815z: Abort 9500 ft. ST&LV due to heavy weather buildup, rain in track area and at field.

Flight C-184-1, Tracks 3 and 7

Track 3 - Upwind, heavy inversion at approximately 6000 ft., heavy haze, with scattered clouds below 6000 ft.-abort.

Track 7 - Downwind, solid cloud deck at approximately 3000 ft.-abort.

Flight C-185-1, Track 7

Heavy haze, no blue sky visible from base altitude estimated visibility, not more than 4 miles.

1534z: Haze layer top at approximately 6500 ft.
1558z: On top of haze at 9500 ft., blue sky overhead.
16l0z: Heavy cloud buildup at south end of track, heavy broken clouds below 9500 ft., broken above.
1626z: Top of cloud deck approximately 7000 ft.
1630z: Inside the haze at 6000 ft.
1651z: Hazy at 9500 ft., broken clouds above.

Flight C-185-2, Track 3

Heavy haze, broken overhead, haze top approximately 7500 ft.

1800z: Shorten V-PRO, climb to base of cloud deck at approximately 3800 ft. Second ST&LV run in the top of the haze, just below cloud base.
1823z: On top of haze at 6200 ft., clear on top. .
1831z: Cloud deck sitting on top of haze at 9500 ft.

Flight C-186-1, Track 7

Heavy haze, slightly blue above from base altitude no clouds visible.

1617z: Haze top at 6500 ft., not as sharp as on C-185 at 6500 ft., some clouds below, broken to scattered below and to the south.

Flight C-186-2, Track 3

Much clearer than C-186-1. Light haze, no clouds overhead.

1803z: Light to moderate haze at 5500 ft.
' 1S17z: Moderate to heavy haze at 5500 ft., no clouds.
lS36z: Moderate to heavy haze below 9500 ft., clear above with scattered clouds to the north.

Flight C-187-1, Track 7

Light to moderate haze. Haze top approximately 6000 ft., with clear blue sky above.

1746z: Thin scattered cloud deck high to the south.
1804z: Running on top fringe of haze a 5500 ft, scattered clouds on horizons.
lS24z: Running in haze top at 9500 ft. scattered clouds below, clear above.
1839z: Passing, light to moderate haze layer at 6000 ft.

Flight C-187-2, Track 4

Heavy cloud buildup in all northeastern tracks.

1945z: Light to moderate haze at 1800 ft. scattered clouds above, hazy blue zenith sky.
1957z: Passing through cloud layer at 5000 ft.
2004z: Running below cloud base, at 3500 ft., in heavy haze.

Flight C-188-1, Track 9

Moderate to heavy haze, smooth, blue sky overhead with no clouds.

1401z: Moderate to heavy haze at 5500 ft., clear overhead.

Flight C-188-2, Track 4

Heavy haze.

1550z: Very heavy haze, estimated visibility 2 miles. Ground Barely visible from 5500 ft. heavier haze at 5500 ft than at 1500 ft.
16l6z: On top at 9500 ft. thin cloud deck at 6000 ft. about 20 miles ahead.

TABLE 5
AIRBORNE DATA SUMMARY
Project METRO Scott AFB, Illinois
August 1971

| Date | Flt No | Start Time | Data Blks | ST&LV Altitudes | V-PRO Filters | Approach Data | Flight Track | Remarks |
|---|---|---|---|---|---|---|---|---|
| 11 Aug 71 | C-180 | 2012z | 228 | 1.2,5.5,9.5,17.5 | 2,3,4,5 | no | 1 | Log has GMT error |
| 12 Aug 71 | C-181 | 1832z | 120 | 1.2,5.5,9.5 | 2,3,4 | yes | 3 | |
| 13 Aug 71 | C-182-1 | 1459z | 113 | 1.8,5.5,9.5 | 2,3,4 | no | 7 | |
| 13 Aug 71 | C-182-2 | 1718z | 112 | 1.5,5.5,9.5 | 2,3,4 | yes | 3 | |
| 14 Aug 71 | C-183-1 | 1452z | 111 | 1.2,5.5,9.5 | 2,3,4 | no | 7 | |
| 14 Aug 71 | C-183-2 | 1723z | 92 | 1.2,5.5 | 2,3,4 | no | 4 | Rain inbound |
| 18 Aug 71 | C-185-1 | 1508z | 118 | 1.8,5.5,9.5 | 2,3,4 | no | 7 | |
| 18 Aug 71 | C-185-2 | 1735z | 115 | 1.5,3.8,9.5 | 2,3,4 | no | 3 | A/C #3 Generator drops off |
| 19 Aug 71 | C-186-1 | 1529z | 111 | 1.8,5.5,9.5 | 2,3,4 | no | 7 | |
| 19 Aug 71 | C-186-2 | 1738z | 114 | 1.5,5.5,9.5 | 2,3,4 | yes | 3 | |
| 23 Aug 71 | C-187-1 | 1730z | 110 | 1.8,5.5,9.5 | 2,3,4 | no | 7 | |
| 23 Aug 71 | C-187-2 | 1931z | 66 | 1.5,3.5 | 2,3,4 | yes | 4 | Short V-PRO, clouds |
| 24 Aug 71 | C-188-1 | 1327z | 109 | 1.5,5.5,9.5 | 2,3,4 | no | 9 | |
| 24 Aug 71 | C-188-2 | 1525z | 120 | 1.5,5.5,9.5 | 2,3,4 | yes | | |

Quantities Measured During ST&LV Runs at Each Altitude

Upper Hemisphere Radiance Distributions
Lower Hemisphere Radiance Distributions
Atmospheric Scattering Coefficients
Horiz ontal Path Function Radiances
Irradiance Levels, Upwelling & Downwelling
Temperature
Pressure
Dewpoint Temperature

Quantities Measured During V-PRO Descents

Atmospheric Scattering Coefficient Profile
Vertical Path Function Radiances
Irradiance profile, Upwelling Only
Temperature
Pressure
Dewpoint Temperature

TABLE 6
GROUND-BASED DATA SUMMARY
Project METRO Scott AFB, Illinois
August 1971

| Date | Data Set Ident | Automatic Data Modes | Manual Data Modes | Remarks |
|---|---|---|---|---|
| 12 Aug 71 | MET-01 | 1-2-3-4-1-5 | | Tape 305A, test |
| 13 Aug 71 | MET-02 | 1-2-3-4-1-5 | | Tape 305B |
| 13 Aug 71 | MET-03 | 3-4 | | |
| 14 Aug 71 | MET-04 | 1 | | Weather abort |
| 18 Aug 71 | MET-05 | 1-2-3-4-1-5 | 21-22 | |
| 19 Aug 71 | MET-06 | 1-2-3-4-1-5 | | |
| 19 Aug 71 | MET-07 | 1-4-1 | | |
| 23 Aug 71 | MET-08 | 1-2-3-4-1-5 | 21 | |
| 23 Aug 71 | MET-09 | 1 | | |
| 24 Aug 71 | MET-10 | 1-2-3-4-1-5 | 21 | |
| 24 Aug 71 | MET-11 | 1-2-3-4-1 | 21 | |

| Data Mode Ident | | Primary Quantity Measurec |
|---|---|---|
| 1: | Full Nephelometer, Σ, β30, β150, calib. | Atmos. Scattering Coeff. |
| 2: | Vertical Plan Scan, sky and terrain rad., Irrad., calib. | Sky & Terrain Radiances |
| 3: | Short Nephelometer, Σ, calib. | Atmos. Scattering Coeff. |
| 4: | Standard CRM, STD, 390, E-CAP, calib. | Apparent Solar Radiance |
| 5: | Standard Sky Scan, UHS, E-CAP, calib. | Sky Radiance Dis tributior |
| 21: | Same as 1, except manual logging. | |
| 22: | Same as 2, except manual logging. | |

October 15, 1971

# LIDAR OBSERVATIONS OF THE AEROSOL STRUCTURE OVER ST. LOUIS, MISSOURI, DURING METROMEX*

Edward E. Uthe

The SRI/EPA Mark VIII** lidar system was used to investigate and record the urban aerosol structure over St. Louis, Missouri, during METROMEX. The lidar used a ruby laser to generate pulses of light energy of about 10 seconds in duration and 0.69 μm in wavelength. These pulses were directed into the atmosphere in a specific direction by an optical system at a rate of up to 20/min. Energy backscattered by the atmosphere was detected in a receiver and evaluated as a function of range from the lidar. The intensity of the signal returned from any given range was dependent upon the concentration, size, shape, and refractive properties of the illuminated particles. Collis (1970) has recently reviewed the lidar technique.

Lidar observations can readily provide quantitative data on aerosol structural features (gradients of relative aerosol concentration, layer height, etc.) that may reveal atmospheric dynamic, physical, and radiative processes important in air pollution problems. (The absolute measurement of aerosol optical parameters and the determination of such physical properties as mass concentration, however, present certain experimental and theoretical difficulties [see Johnson and Uthe (1971)] and this has not been attempted in this data collection program.)

In the observations made in St. Louis the backscatter signatures were electronically corrected for an inverse range squared dependence, logarithmically amplified, and stored on a magnetic video disc recorder. Each track of the disc (1000 tracks available per disc) can contain up to 160 lidar signatures in a format that permits them to be played back through the system to produce an intensity modulated "picture" display. An example of the data display and a readily apparent analysis is presented below.

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vertically upward at a fixed location within the city, approximately 1/3 mi north of the Gateway Arch on 13 August 1971. The height/time cross section presented in Figure 1(b) started at 0705 and used a lidar pulse rate of 10/min. The data from a radiosonde launched near the Arch at 0700 are shown in Figure 1(a). The sky was overcast with the cloud base at 2.5 km and a dense haze layer below. Visibility was estimated to be on the order of 2 mi. The A-scope presentation (received signal as a function of range) of the 0721 lidar firing [Figure 1(c)] reveals that the signal return from beyond the cloud was below the receiver noise level, so the relative density of the aerosol above the cloud is unknown. A dense aerosol layer extended from the surface to a height of 0.25 km and most likely represented particulate matter newly injected or formed in the atmosphere. The vertical profiles of temperature and dew point [Figure 1(a) ] show a low-level temperature inversion extending to a height corresponding to the top of this near-surface aerosol layer. A change of lapse rate also marks the cloud base.

After 0734, the height/time cross section was continued with a lidar pulse rate of 2/min [Figure 1(e)]. The winds throughout the day remained from the south at 5 to 7 mi/hr. As the day progressed, higher level cloud layers were detected by the lidar. Dark areas above a cloud result from the increased attenuation of the laser energy along the roundtrip path through the cloud. The lower overcast "burned off" at about 1030, and the aerosol optical density within the haze layer gradually decreased. This decrease was probably caused by a general decrease in size of hygroscopic particles with decrease of relative humidity that accompanies warmer temperatures. During the day, depth and optical density of the near-surface layer gradually increased. The top of the aerosol layer at 2.5 km dissipated, and a new upper boundary was established near 2 km. Beginning at 1215 active thermal convection increased the height of the lowest aerosol layer 0.75 km/hr. A temperature sounding made at 1230 [Figure 1(d)] from the Arch shows the near adiabatic lapse rate associated with the heating of the lowest atmospheric layer and a change of lapse rate at the tops of haze layers. Clear air convective cells are revealed by consistent wave structure of the aerosol layer boundaries during the 1310-1330 time period [Figure 1(f)]. Convection carried the relatively warm and dirty air up to the 2-km boundary and into the relatively clean and cool air, causing convective cloud formation. These clouds, identified in Figure 1(f) by very bright areas with very dark areas above, occurred at maximum heights of the haze layer which seem to show a periodic nature during the interval from 1500 to 1800.

During other data collection periods (Table 1) precipitation cells developed and the washout of the urban aerosol layer was observed. Still other data were collected with the lidar in a mobile configuration and a lidar pulse rate of 20/mile. These data, to be reported upon later, depict the spatial and temporal variation of the urban haze layer in St. Louis and vicinity.

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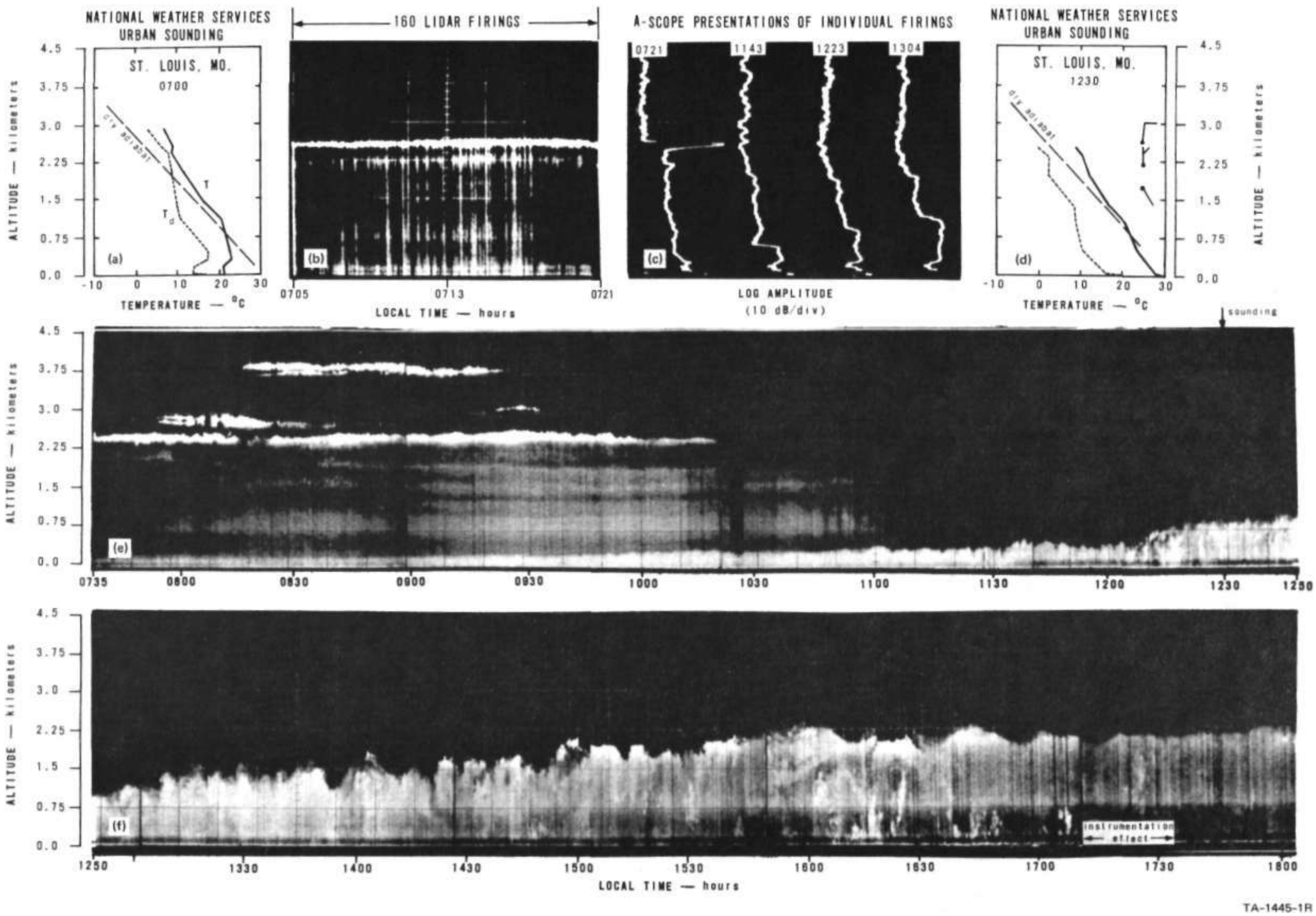


FIGURE 1 HEIGHT/TIME CROSS SECTION OF THE AEROSOL STRUCTURE OVER ST. LOUIS, MISSOURI ON 13 AUGUST 1971 AS OBSERVED BY SRI/EPA MARK VIII LIDAR SYSTEM

Table I
SUMMARY OF LIDAR DATA COLLECTION
METROMEX 1971, ST. LOUIS, MO.

| DATE | TIME* Start-End | MOBILE(M)-pulses/mile STATIONARY(S)-pulses/min | NO. SHOTS | SITE/ROUTE/REMARKS |
|---|---|---|---|---|
| 9 Aug. | 1055-1111 | S-10 | 160 | Inst. 270/U.S. 67 Junction |
| | 1155-1203 | S-20 | 160 | South of Arch on Riverfront Drive |
| | 1650-1658 | S-20 | 160 | Bel Air East parking lot (4th Street and Lucas, 1/3 mi N. of Arch) |
| 10 Aug. | 0700-0705 | S-20 | 106 | Bel Air East/generator failure |
| | 0955-1003 | S-20 | 160 | |
| | 1624-1632 | S-20 | 160 | Generator overhauled (1100-1400) |
| | 2058-2106 | S-20 | 160 | |
| 11 Aug. | 0705-0713 | S-20 | 160 | Bel Air East |
| | 0731-0940 | S-4 | 480 | |
| | 0947-1825 | S-2 | 960 | |
| | 2126-2246 | S-2 | 160 | |
| 12 Aug. | 0710-0726 | S-10 | 160 | Bel Air East |
| | 0820-0836 | S-10 | 160 | |
| | 0941-1600 | M-20 | 2,982 | U.S. 40(W)/Inst. 244(N)/Inst. 270(E)/Inst. 55(SW)/Inst. 244(N)/U.S. 40 (E)/Inst. 70(N)/Inst. 70(S) |
| 13 Aug. | 0705-0721 | S-10 | 160 | Bel Air East |
| | 0734-1815 | S-2 | 1,250 | |
| 14 Aug. | 1335-1355 | S-2 | 40 | Bel Air East/Data collection initiated 40 min after start of rain |
| | 1355-1519 | S-10 | 600 | |
| 15 Aug. | 1030-1150 | S-2 | 160 | Bel Air East |
| | 1520-1528 | S-20 | 160 | |
| | 1800-1808 | S-20 | 160 | |
| 16 Aug. | 0705-0721 | S-10 | 160 | Bel Air East |
| | 0726-1130 | S-2 | 480 | |
| | 1217-1553 | M-20 | 2,498 | Inst. 55 (N from Inst. 244 to Inst. 270)/Inst. 55 (S to Lindbergh Bl)/ Inst. 55 (N to Inst. 270)/Inst 270(W)/Alton (Metromex meeting) via U.S. 67 |
| 17 Aug | 1057-1113 | S-10 | 160 | Bel Air East |
| | 1140-1215 | M-20 | 320 | To Scott Air Force Base via U.S. 460/U.S. 50 By/Illinois 161 |
| | 1455-1511 | S-10 | 160 | Scott Air Force Base |
| | 1706-1745 | M-20 | 480 | To Bel Air East via Illinois 161/U.S. 460 |

*Local Time-Central Daylight

Table I (Continued)
SUMMARY OF LIDAR DATA COLLECTION
METROMEX 1971, ST. LOUIS, MO.

| DATE | TIME* Start-End | MOBILE(M)-pulses/mile STATIONARY(S)-pulses/min | NO. SHOTS | SITE/ROUTE/REMARKS |
|---|---|---|---|---|
| 18 Aug. | 0707-0723 | S-10 | 160 | Bel Air East |
| | 0723-1102 | S-2 | 450 | |
| | 1205-1650 | M-20 | 3,153 | Inst. 55 (S from Inst. 270)/U.S. 66(S)/Inst. 44 (S to Pacific)/N to Inst. 270 via route above/Inst. 55 to Bel Air East |
| 19 Aug. | 0710-0726 | S-10 | 160 | Bel Air East |
| | 0729-1934 | S-2 | 1,600 | |
| 20 Aug. | 0721-1549 | M-20 | 5,148 | Inst. 70 (N from Bel Air East)/Inst. 244(S)/Inst 55(N)/Inst. 70(N)/Inst. 244(S)/Inst. 55(N)/Inst. 70(N)/Inst 244(S) generator failure (1228)/ Inst. 55(N)/Inst. 70(N)/Inst 244(S) generator failure (1425)/Inst. 55 (N)/Inst 70(N) to Bel Air East |
| 21 Aug. | 1104-1109 | S-20 | 70 | St. Louis University-north side of Earth Sci. Build/90° angular scan(SE) for data comparison with microwave thermosonde |
| | 1110-1142 | S-5 | 160 | |
| | 1145-1147 | S-20 | 70 | 90° angular scan |
| | 1205-1302 | S-20 | 960 | Rain begins |
| | 1304-1403 | S-10 | 480 | |
| | 1450-1453 | S-20 | 70 | 90° angular scan |
| 23 Aug. | 1000 ---- | S-5 | | Bel Air East/Start of 32 hr run |
| 24 Aug. | ---- 2048 | S-5 | 9,760 | Bel Air East |
| 25 Aug. | 0715-1643 | S-5 | 2,880 | Bel Air East |
| 26 Aug. | 0750-1350 | M-20 | 3,706 | Inst. 70 (N from Bel Air East)/Inst 70 (S from Inst. 244)/ Inst. 55 (S to Lindbergh Bl)/Inst 55(N)/Truck failure/Inst 70(N)/Inst 70 (S from Inst. 244)/Inst. 55 (S to Lindbergh)/Inst. 55(N)/Inst. 70(N)/Inst. 70 (S from Inst. 244)/Inst. 55 (N over river)/Illinois 111 (N to Civic Memorial Airport to demonstrate lidar) |
| | 1634-1702 | M-20 | 508 | Illinois 111 and Inst. 55 (S from airport to Bel Air East) |
| 27 Aug. | 0925-0941 | S-10 | 160 | East side of Forest Park |
| | 1000-1015 | Manual | 100 | Calibration data with white target |
| | 1024-1050 | Manual | 100 | Polorization experiments with white target |
| | 1052-1108 | S-10 | 160 | |
| | 1120-1400 | | 0 | Truck breakdown/tow/repair |
| | 1420-1540 | S-2 | 160 | North of Anheuser Busch/Water supply off/output energy drops |
| | 1547-1603 | S-10 | 160 | |
| | | Total No. Shots | 43,091 | |

* Local Time-Central Daylight