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*Interim Report No. 1* *February 1967*

# URBAN CLIMATOLOGICAL STUDIES

*Prepared for:*

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310

CONTRACT OCD-PS-64-201
UNDER WORK UNIT 1235A

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STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

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*By:* F. L. LUDWIG

*SRI Project MU-4949-580*

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This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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Urban Climatological Studies

By F. L. Ludwig. Stanford Research Institute, February 1967.
Prepared for Office of Civil Defense, Department of the Army--OSA, Washington, D.C. under Contract OCD-PS-64-201, work unit 1235A.

## SUMMARY


In an effort to determine the nature of temperature and humidity variations within an urban area, an extensive program of temperature and humidity measurements has been undertaken for The Office of Civil Defense (Contract No. OCD-PS-64-201). In this report, the instruments and field program are described. Preliminary results of the data analysis are also presented.

The first phase of the program involved the design and construction of a portable temperature measuring system. A system was built that uses ventilated thermistor elements to measure wet and dry bulb temperatures at heights of 0.3 meter and two meters. The elements are shielded from radiation and can be mounted on an automobile or truck bumper. The temperatures are recorded on chart paper by a unit carried within the vehicle. Accuracies achieved with this instrumentation were about ±0.25°C. Two complete systems were built so that two separate vehicles could be used in the surveys.

Three cities were investigated: San Jose, California; Albuquerque, New Mexico; and New Orleans, Louisiana. Two routes were planned for each city. Each route was about 15 to 20 miles long and took about one hour to traverse. The routes were selected to cover as wide a variety of neighborhoods as possible, and to extend from the core of the city to the edges. These routes were driven several times a day by each of the equipped vehicles. While driving, the temperature records produced were annotated with information concerning locations, times, and special weather encountered. About three weeks were spent in each city.

Approximately 35 to 40 thousand separate temperature readings were transferred from the field records to punched cards and preliminary processing completed. The punch card data were transferred to magnetic tape and were edited for errors, sorted, and consolidated. These processed data were interpolated by computer to give temperature values

for integral hours. These interpolated temperatures were computer averaged for about 50 selected locations in each city. In addition to conventional averages, averages of relative temperatures were obtained. To obtain these relative averages, each temperature to be averaged had subtracted from it the noon temperature from the local airport. Dry bulb airport temperatures were subtracted from dry bulb temperatures, and wet bulb from wet bulb. The averages of the relative temperatures have been analyzed and these average fields are presented in the report along with the average deviations of airport dry bulb temperature from its noon value. Also presented are the changes from hour to hour of the averages of relative temperatures for different types of neighborhoods in each city.

These preliminary analyses indicate that in the daytime downtown areas tend to raise the temperature by about 1/2°C. This figure is an estimate of the effect of the built-up area on temperature--separate from topographical influences. Areas that are shaded by trees or have large open grassy spaces also produce temperature changes of about 1/2°C. These areas are cooler than unshaded built-up surroundings. The geographical effects that are discernible in the preliminary results are generally larger than the effects produced by the city itself. The geographical features that produce the effects referred to are San Francisco Bay in San Jose, Lake Pontchartrain in New Orleans, and the changes in elevation in Albuquerque.

The report concludes with a section describing future plans. These plans include more detailed treatment of the available data using empirical and theoretical approaches from the literature to describe temperature changes in terms of meteorological and urban factors. It is also planned to incorporate information from other studies concerning the effects of height above the ground and instrument exposure. Some additional field studies are planned. These studies, including some 24-hour measurement periods, are intended to supplement our knowledge of diurnal variability of city-country temperature differences and to answer some questions concerning the effect of city size on these effects.

Detailed route descriptions and an annotated bibliography are included as appendices.

## ABSTRACT

The report describes portable automobile-mounted, recording, temperature measurement systems using ventilated radiation-shielded thermistor elements to measure wet and dry bulb temperatures at heights of 0.3 and 2 meters with an accuracy of about ±0.25°C. The units were used on two vehicles to survey horizontal temperature fields in San Jose, Calif.; Albuquerque, N.M.; and New Orleans, La., during the summer of 1966. About three weeks were spent in each city, covering areas from the city's center to its edge. Chart records of temperature were transferred to punched cards and processed. They were interpolated to common hours and averaged for about 50 selected locations in each city. The averages are in a relative form, where each of the 18 to 20 thousand individual temperatures had subtracted from it that day's noon airport temperature. Relative wet-bulb temperature fields are also presented. Daytime results are stressed. Preliminary analyses indicate that the effect of built-up areas, as distinct from other influences, is to raise the temperature by about 1/2°C during the day. Shaded or grassy spaces are about 1/2°C cooler than their unshaded surroundings. Future plans are discussed.

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# I INTRODUCTION

In city areas, most readily available climatic data come from only one or two locations. Most commonly, meteorological instruments are located at an airport at a height of six or more feet above ground level. Sometimes data are taken on the top of a building in the city's downtown area. A question arises as to whether such data are representative of the climate at other locations within the city. Precise knowledge of climate is critical to the specification of ventilation requirements for civil defense shelters. For this reason Stanford Research Institute, for the Office of Civil Defense, is studying the effects of cities on temperature and humidity. This is the first report describing the results of this program.

The report emphasizes temperature and humidity conditions during the summer months and during the day. It also emphasizes conditions in hot parts of the country: San Jose, California; Albuquerque, New Mexico; and New Orleans, Louisiana. It is these hot conditions that are most crucial to ventilation requirements for shelter. Also, most available information on urban temperature effects stresses nighttime conditions during the colder seasons. Thus, the biggest gap in present knowledge of climate occurs at the point where we most require information.

This report describes the instrumentation that was developed to measure and record temperature and humidity, the program of measurements conducted in three cities, the data reduction techniques, and the preliminary results of the data analysis. Future plans for more detailed interpretation of the data already collected and plans for supplemental data collection are also described.

The sections describing instrumentation and methods are included because they are important to the evaluation of the results, and constitute an important part of the total program. However, these sections are not necessary for the comprehension of the results or future plans.

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## II INSTRUMENTATION

Certain requirements had to be met in the design of the instrumentation. Because much of the work had to be done far from Institute facilities, it was desirable that the instrumentation be kept simple to decrease the chances for breakdown and the need for maintenance. In addition, limitations in the number of personnel dictated that the equipment be operable by one man while he was driving. To minimize the problems of data reduction, it was virtually essential that the results be directly interpretable without resorting to conversion tables or non-linear calibrations.

Continuously recorded data offer significant advantages over data read or recorded only at fixed points. If interpretation of data indicates some interesting features intermediate to preselected points, the original data can be consulted and intermediate values determined. Also, a permanent record is available to check for possible errors in transcribed data.

### A. Mobile Temperature Measuring Equipment

#### 1. Thermistors

The sensors used in the study were composite thermistor elements matched so as to follow equivalent calibration curves. They had linear response characteristics between -5°C and +45°C. Four sensors were used with each vehicle; two were used to measure dry bulb temperatures and two to measure wet bulb temperatures.

These composite thermistor elements* consist of separate resistors and the sensing element which has two thermistors in a single bead. The bead dimensions are approximately 0.15 inch in diameter by 0.25 inch long.

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* Yellow Springs Instruments, Yellow Springs, Ohio, Part No. YSI 44202.



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The arrangement of these resistors and thermistors in the sensor network is shown in the next section.

The output of the network is a voltage that is a linear function of temperature and applied voltage. Over the range of temperatures from -5°C to +45°C, the deviation from linearity is equivalent to less than ±0.1°C, according to the manufacturer's specifications. The manufacturer also claims that each of these elements reads within ±0.15°C of the same calibration and that they can be interchanged. The limits of error should be approximately the sum of the manufacturing tolerance and the linearity deviation cited above, that is, approximately ±0.25°C. Field comparisons with mercury in glass thermometers have confirmed this.

The time constant* of the sensors in free, still air is about 10 seconds according to the manufacturer. This was not checked during the program, but it is probably a nearly correct value for the conditions under which the dry bulb measurements were taken in our setup. Estimates of the wet bulb thermistor time constant were made from the time it took for the thermistor to read a steady value after the wick had been wet. This was found to be approximately a half minute.

## 2. Bridges and Recorders

A schematic diagram of the circuitry used for the temperature recording system is shown in Fig. 1. Essentially, the circuitry is a Wheatstone bridge with a recorder connected across the output. The high impedance necessary to maintain the linearity of the system was achieved through the use of a transistorized operational amplifier† between the bridge output and the recorder.§ The operational amplifier was adjusted to have a zero db gain.

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* The time constant is the time required for the sensor to indicate 63% of an abrupt change in temperature.

† Nexus Research Laboratory Inc., Canton, Mass., Model 2LV-1.

§ Rustrak Instrument Co., Inc., Manchester, N.H., Model 81137.

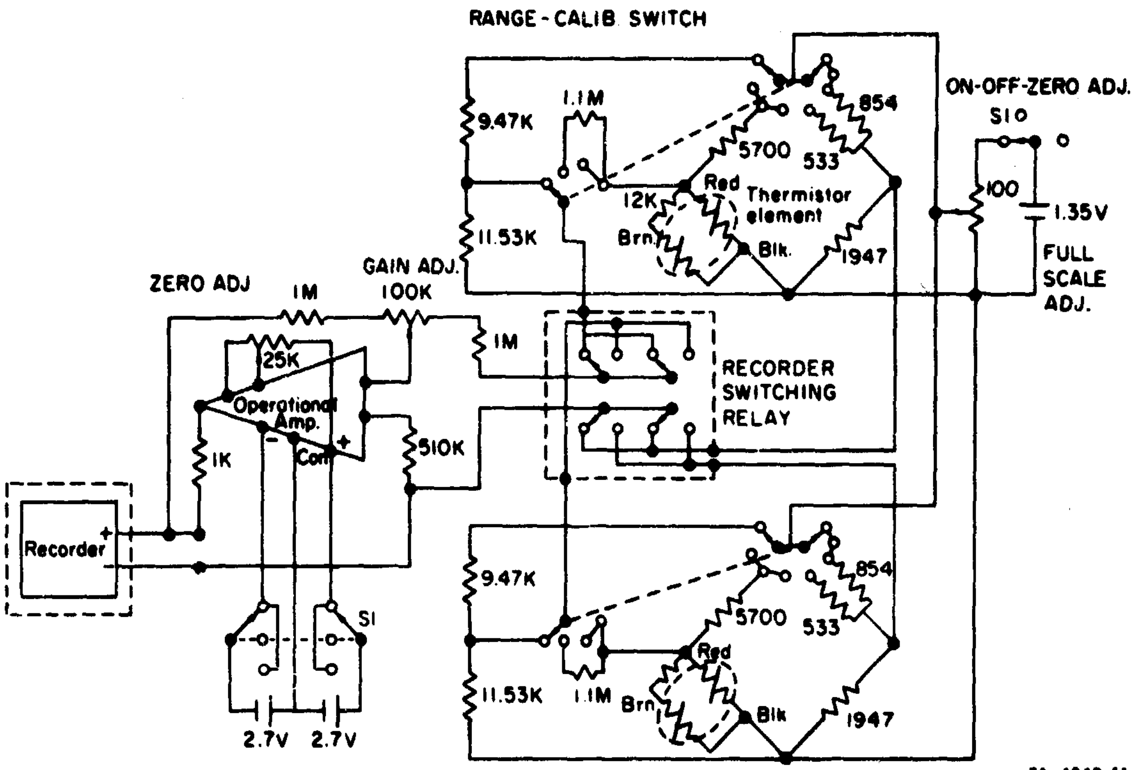


FIG. 1 SCHEMATIC DIAGRAM OF TEMPERATURE RECORDING SYSTEM

A separate bridge was used for each temperature element. The input to the amplifier was alternated between the wet and dry elements from the same level at intervals of about one second. The recorder has a built-in synchronous motor-driven relay which does this switching of inputs. The recorder is inkless and operates by striking the indicator needle against pressure-sensitive chart paper. The strike frequency is about once per second and is controlled by a cam-operated striker. In our operation the input to the recorder was switched between strikes, thus alternating between points for the wet bulb temperatures and for the dry bulb temperatures. The two-second spacing between recordings for a given sensor resulted in traces that were essentially continuous. The chart speed was nominally twelve inches per hour.

Stable voltages for the bridge and amplifier were supplied by mercury cells. Specially wound precision resistors were used in the bridges. Each bridge could be operated on three different temperature ranges. For the two lower ranges the resistances were calculated to give a zero millivolt output for temperatures of 5°C or 20°C, depending on the range setting, and a hundred millivolt output for 30°C or 45°C. For the highest range, which was to be used only if temperatures exceeded 45°C, a resistance was added in series with the sensing element. This highest range is, therefore, nonlinear in response. It never had to be used.

A fourth or calibration position on the range switch replaces the thermistor in the low temperature range circuit with a precision resistor that has the same resistance as the element at 30°C. On this setting the potentiometer that supplies the input voltage to the bridge is adjusted to give a full-scale recorder reading. Small changes in amplifier gain are compensated for in this way. The ratio of the resistance of the potentiometer to that of the bridge is small so that changes in bridge resistance do not affect the applied voltage, and the response remains linear. It is also possible to adjust the amplifier bias so that its output is zero with a zero input. The zero and full-scale adjustments were made before and after a run and were frequently checked and adjusted during a run. The zero drift was usually small. Full-scale drifts of about a half-degree centigrade were fairly common during the first hour's operation, but generally declined to a tenth-degree or less after the system had completely warmed up.

Wet and dry bulb temperatures were measured at each of two levels in each vehicle. There were two of the circuits shown in Fig. 1 for each vehicle. These two circuits with their two recorders and sets of controls were housed in a single box. This is shown in Fig. 2.

The power necessary to operate the recorders was supplied by an inverter* that converted the 12-volt DC of the car's electrical system to a nominal 60 cycle, 120 volt AC.

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* Electro Products Laboratories, Inc., Chicago, Ill., Model TI 100.

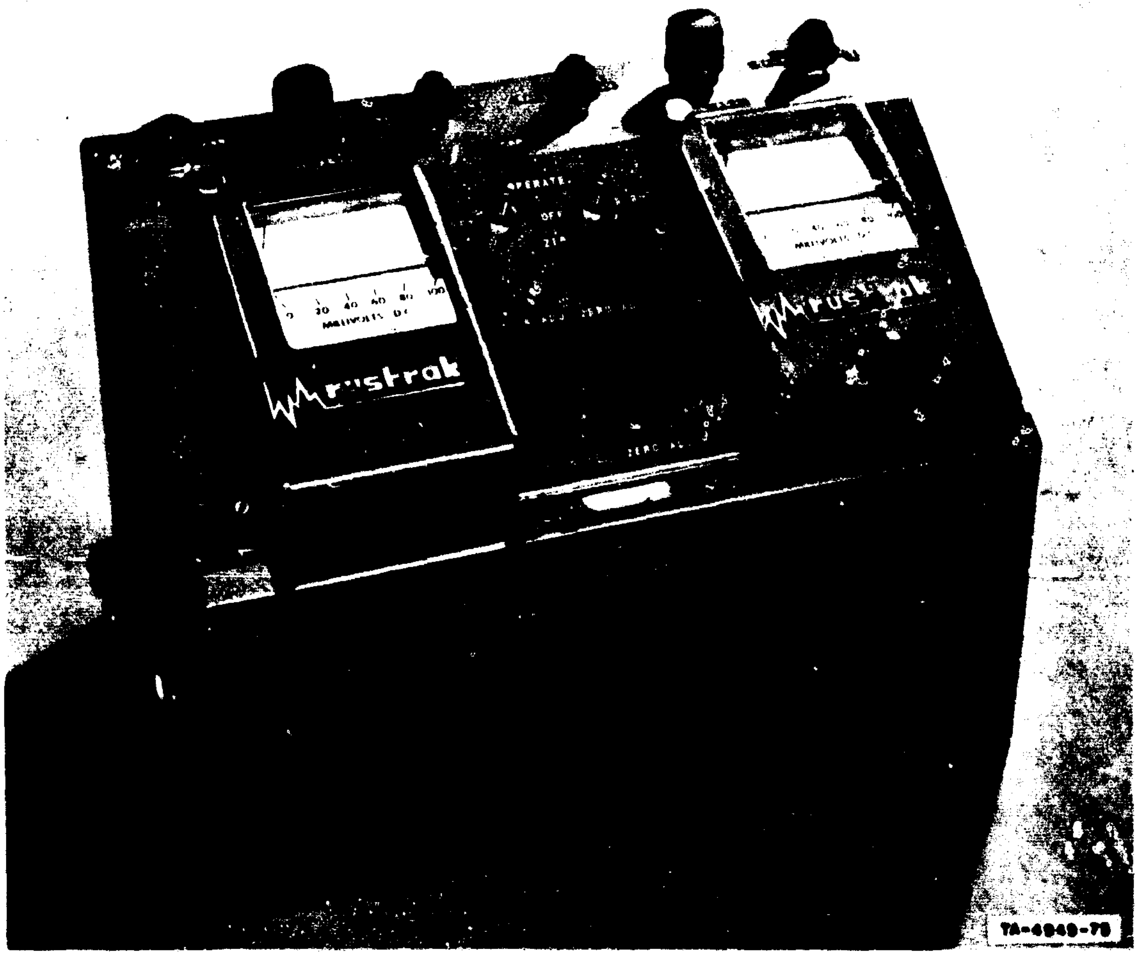


FIG. 2 TEMPERATURE RECORDER UNIT

3. <u>Mounting and Shields</u>

The mounting arrangements for the sensors is shown schematically in Fig. 3. Figure 4 shows the equipment as it appeared when mounted on the vehicles. The blower shown in Fig. 3 draws air into the two inlets and past the thermistors. Some ventilation is provided even when the vehicle is standing still. This small blower is rated at about 50 cubic feet per minute. From the dimensions of the system, it can be calculated that the air flow past the sensors is about 12 ft/sec or 7 knots. This is the minimum ventilation recommended for a wet bulb thermometer (Meteorological Office, Great Britain, 1956, p. 176). Inasmuch as most measurements were made with the vehicle in motion, the ventilation provided was more than adequate.

The sensor mounts were designed so that the lower thermistors would be at a height of about 0.3 meter and the upper ones at about two meters.

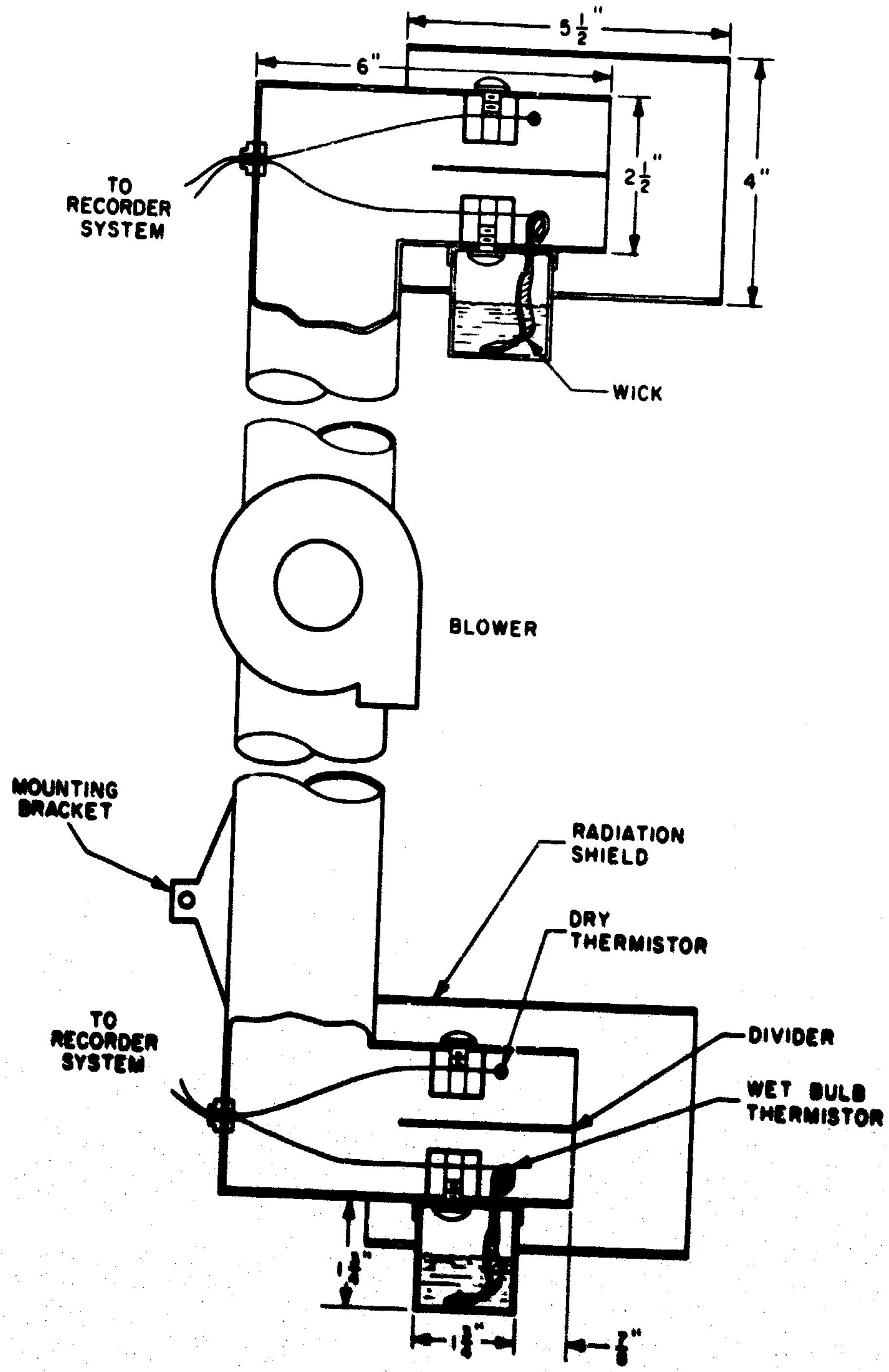


FIG. 3 DIAGRAM OF TEMPERATURE SENSING UNIT


FIG. 4 TEMPERATURE SENSING UNITS
ATTACHED TO SURVEY VEHICLES

Since one unit was to be used with an Institute-owned compact van and the other with a rented compact sedan, there were differences in the placement of the mounting brackets to compensate for differences in bumper heights. This was generally satisfactory except in New Orleans and for two night runs in San Jose where it was necessary to use the equipment designed for the sedan on a truck. This resulted in the equipment being about 6 inches higher than desirable.

The equipment was designed so that it could be mounted without having to make any permanent alterations in the vehicle. The tubing and blower apparatus were attached to the bumper using a detachable trailer hitch. The upper end of the unit was supported with two metal rods that were connected to a ski rack on top of the vehicle. The wires from the thermistors and blower were brought inside the vehicle through the window. The inverter was connected to the vehicle's electrical system at the fuse panel under the dash. Generally, it took about an hour to make the initial installation. After the initial installation, the equipment could be removed or installed in a few minutes because many of the parts were left attached, e.g., the rack on top of the vehicle, the trailer hitch, and the inverter.

The aluminum radiation shields were painted white to reflect radiation and minimize errors from this source. The inner tubing was unpainted. The thermistor was supported by its own wires and insulation which passed through a piece of Lucite plastic bolted to the tubing.

The wick for the wet bulb sensor was made from a piece of cotton shoelace that had been boiled in distilled water before use. The wick was rinsed with distilled water at least once a day. The rinsing should have removed most of the water-soluble contaminates which would be most likely to affect the wet bulb reading. However, it seems likely that the accumulation of dirt may have caused some small errors in the observations. Such errors would generally be in the direction that would make the measured wet bulb temperature too high (see, for example, Gregory and Rourke, 1957). The magnitude of the errors is discussed in the following section. The fragility of the sensors prevented a more thorough cleaning.

4. Calibration Checks

Forty comparisons were made in the field between mercury-in-glass wet bulb readings and those from the wet bulb thermistor. The results showed that the two sensors were within ±0.3°C of each other for 75% of the observations. The maximum discrepancy observed was 1°C. Since both the median and the mode of the distribution of differences between thermistor and mercury-in-glass wet bulb readings was zero, no attempt has been made to correct for contamination errors in the wet bulb measurements.

As has already been mentioned, the thermistor manufacturer claims that an accuracy of ±0.25°C can be achieved with the thermistor elements. This was generally confirmed by comparisons made between dry thermistor readings and mercury thermometer readings. Of the 48 comparisons made, all but one were within 0.3°C and 90% were within 0.2°C. There was a slight bias; the median of the observed differences was 0.1°C with the thermistors reading slightly lower than the mercury thermometer.

B. Hygrothermographs

In addition to the mobile temperature measuring equipment, two standard hygrothermographs were used in the program. The primary purpose for securing hygrothermograph records was to aid the interpolation and interpretation of the results obtained from vehicle traverses. The accuracy of these instruments is much poorer than that of mobile sensors so the records will only be used to estimate the nature of temperature changes with time. These Bendix-Friez* hygrothermograph employ a bourdon tube temperature sensor and a hair relative humidity element. Charts were changed daily. These instruments were generally placed in small instrument shelters (about 1-1/2 x 1 x 1-1/2 ft) like the one shown in Fig. 5. These shelters were made from small louvered doors and were painted white to minimize radiation effects. The heights of the shelters were nominally two meters. At two locations, one in San Jose and one in New Orleans, the instruments were placed in conventional Weather Bureau style shelters.

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* Friez Instrument Division, Bendix Aviation Corporation, Baltimore, Md., Model 594.

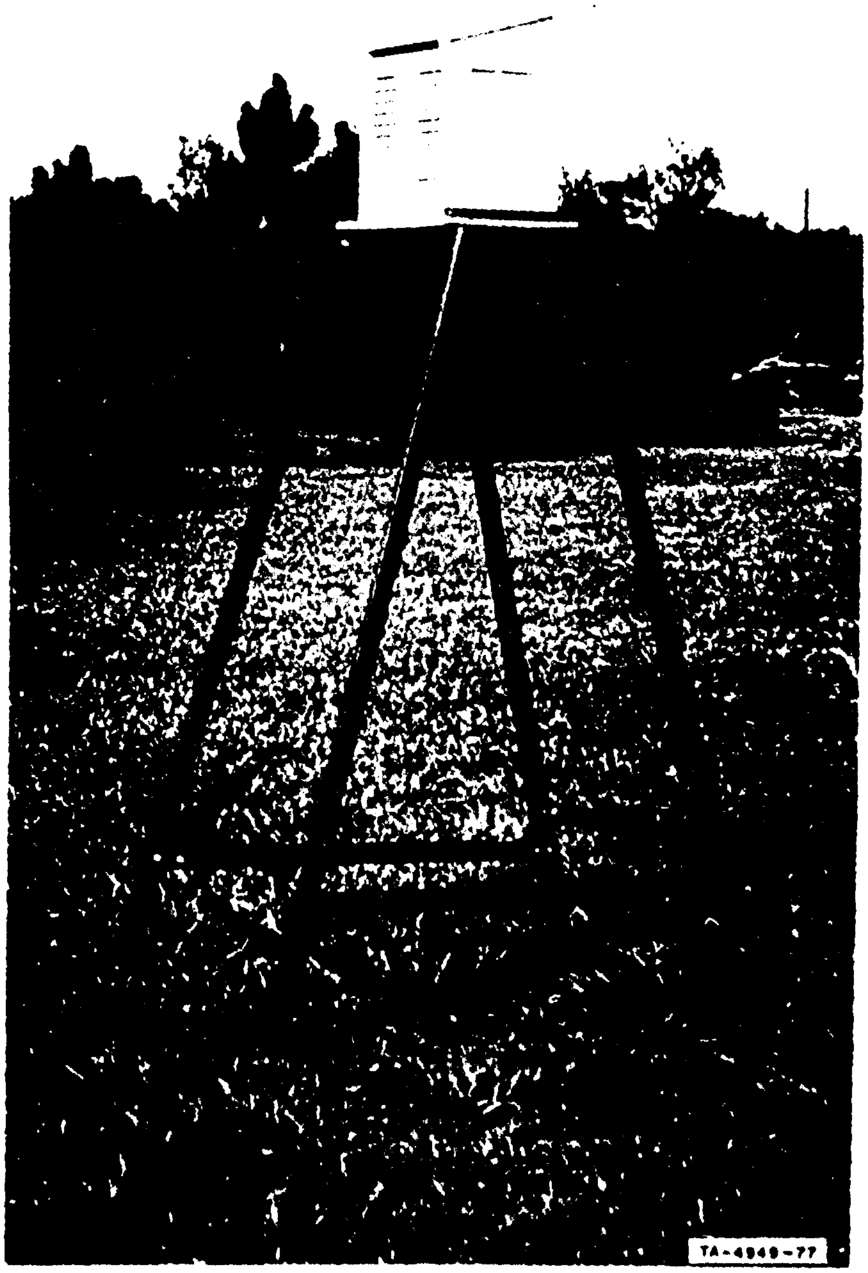



FIG. 5 INSTRUMENT SHELTER

## III FIELD OPERATIONS

### A. General

The field operations consisted of traverses of specified routes in each of the three cities studied: San Jose, Albuquerque, and New Orleans. Temperatures were continuously recorded during the traverses and the times at which preselected points were passed were marked on the temperature charts. Also noted were special weather occurrences such as rain, lightning, etc. Cloud cover observations were recorded several times a day.

The various routes were each about 15 to 20 miles long and took about one hour to complete. There were two routes per city. Each route was planned to reach from the central core of the city to the outskirts and to pass through as many different kinds of areas as was possible. The downtown areas were better covered than the environs. The routes are described in detail in the Appendix A.

The turns on each route were numbered consecutively. These turn numbers were noted on the temperature chart, along with the time. When there was a long stretch between turns, intermediate cross streets were often entered on the record. Usually a stop was made at the beginning or end of a route and once near the middle to check the zero and full-scale adjustments of the instrumentation.

The two drivers alternated between routes so that no bias would be introduced because one set of equipment was always used on the same route. Because this program's emphasis was on warm weather conditions, most, but not all, measurements were taken during the daytime, from late morning through mid-afternoon. Table I shows the days of operation in each city along with the approximate hours of operation. Daytime measurements were usually concluded at times which were later than the times of occurrence of the maximum temperature.

Table I

PERIODS OF FIELD OPERATION

| San Jose | | Albuquerque | | New Orleans | |
|---|---|---|---|---|---|
| Date (1966) | Time (LST) | Date (1966) | Time (LST) | Date (1966) | Time (LST) |
| June 28 | 0955-1435 | July 11 | 1420-1700 | July 26 | 0840-1610 |
| 29 | 0850-1530 | 12 | 1035-1620 | 27 | 0935-1540 |
| 30 | 1220-1450 | 13 | 1330-1605<br>1935-2205 | 28 | 1000-1600<br>1905-2130 |
| July 1 | 0830-1405 | 14 | 1010-1625 | 29 | 0930-1540 |
| Sept 7 | 0840-1530 | 15 | 0950-1510 | 30 | 0950-1600 |
| 8 | 0800-1335 | 16 | 0830-1600 | 31 | 0935-1555 |
| 9 | 0820-1340 | 17 | 0925-1605 | Aug 1 | 0935-1540 |
| 12 | 0805-1340 | 18 | 1000-1520 | 2 | 0910-1250 |
| 13 | 0805-1355 | 19 | 0940-1505 | 3 | 0900-1540 |
| 14 | 0800-1330 | 20 | 0250-0725 | 4 | 0230-0640 |
| 15 | 0755-1335 | Aug 18 | 1305-1625 | 11 | 1025-1640 |
| 16 | 0805-1335 | 19 | 0950-1320<br>1800-2030 | 12 | 0900-1230<br>1735-1955 |
| 25 | 1830-2220 | 20 | 0940-1610 | 13 | 0930-1400<br>2125-2400 |
| 26 | 2100-2400 | 21 | 0850-1420<br>2140-2400 | 14 | 0000-0200 |
| 27 | 0000-0035 | 22 | 0000-0155 | | |

Driving speeds were kept below 45 mph, and speeds this high were only reached in the open areas surrounding the cities; more typically, the speeds were 20 to 30 mph.

B. San Jose

The routes used in San Jose are shown in Fig. 6. This figure gives the turn numbers and includes some intermediate points that were used in the data analysis. The photographs in Fig. 6 show some typical locations around the city. Each picture is connected to the approximate point on the map where the picture was taken; the arrows at the ends of the

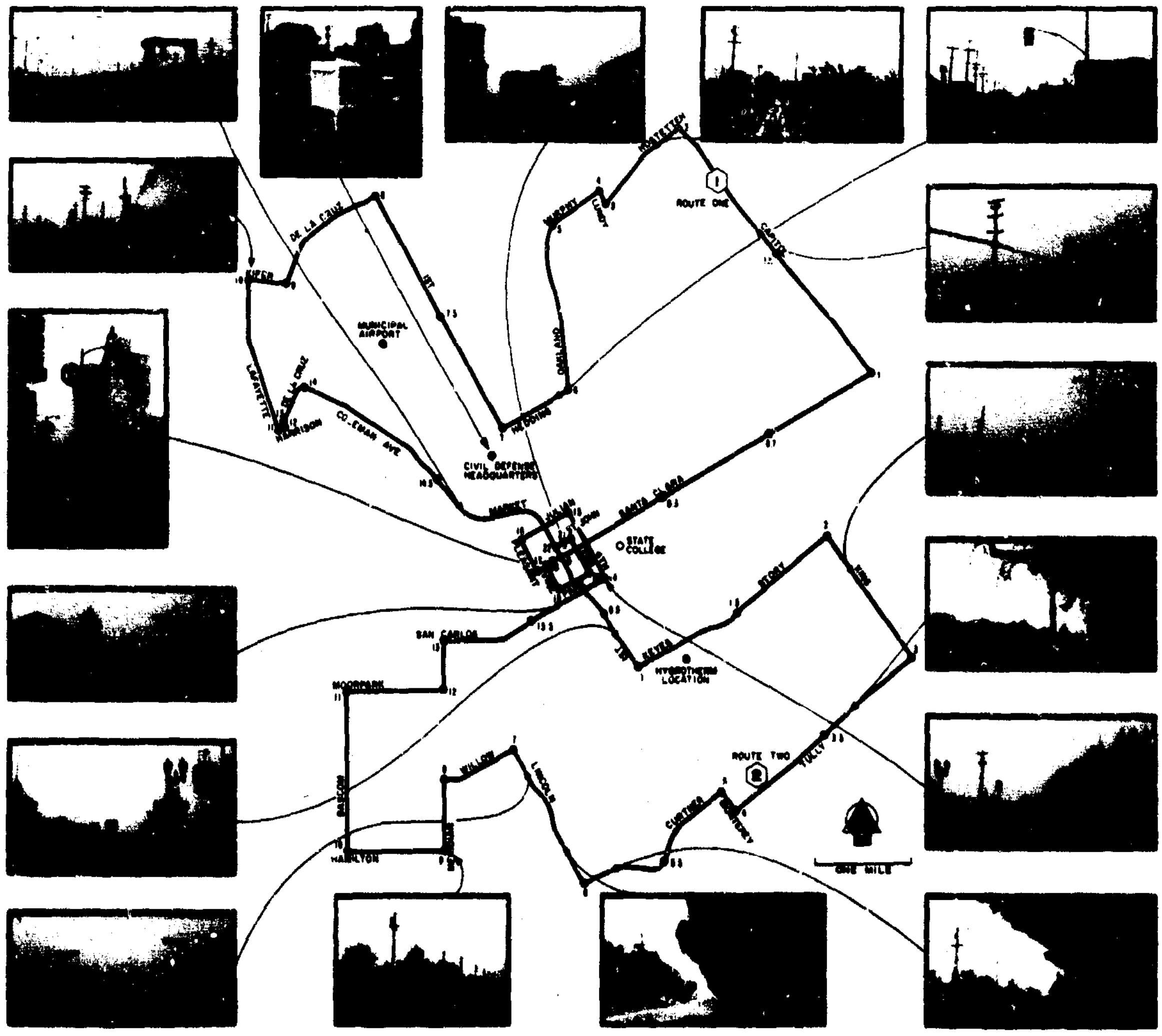



FIG. 6 SAN JOSE ROUTES WITH PICTURES OF TYPICAL AREAS

connecting lines show the direction in which the pictures were taken. These pictures were all taken in December when the deciduous trees were without leaves. Of course, during the periods of measurement in San Jose the leaves were on the trees. The pictures of the other two cities, shown in Sections IIIC and D, were taken during the period of operation.

Figure 7 shows the built-up areas and topography (U.S. Geological Survey, 1961) of the San Jose area. The cross-hatched areas indicate the built-up sections. Detailed descriptions of the routes are given in the Appendix A. As can be seen in Fig. 7, the area covered by the routes in San Jose is relatively flat. The elevations range from about 30 ft above sea level at Turn 8 on Route No. 1 to about 175 ft above sea level at Turn 10 on Route No. 2.

Although San Jose itself is relatively flat, the surrounding terrain is not. The city lies in a valley oriented in a northwest-southeast direction between two mountain ranges, the Diablo Range to the northeast with peaks to about 4000 ft, and the Santa Cruz mountains to the southwest with peaks to about 3000 ft. The foothills of the Diablo Range can be seen in the northeast corner of Fig. 7. Generally, the valley in which San Jose lies rises gradually toward the southeast starting from the lower end of San Francisco Bay. The end of the Bay is about ten miles northwest of the downtown area; the downtown area is approximately outlined by the small square which the routes form in the center of the map.

The population of the San Jose area is about 850,000 (U.S. Bureau of the Census, 1966). Much of the area surrounding the core of the city is devoted to orchards, but there are also substantial areas of farmland. As can be seen from Fig. 7, the center part of the city is rather solidly built up.

One of the hygrothermographs used in this program was located in a conventional Weather Bureau type shelter that belonged to the Office of Civil Defense. This shelter is pictured in Fig. 6. The area immediately surrounding the shelter had a low shrubbery ground cover. The one-story Civil Defense Center was about 50 ft west of the shelter. There were no

U.S. Geological Survey, 1961

FIG. 7 SAN JOSE ROUTES SHOWING TOPOGRAPHY AND BUILT-UP AREAS other nearby obstructions to ventilation. The elevation of this location was about 65 ft.

The other hygrothermograph was located on San Jose State College property near 9th and Humboldt. This location had a one-story building about 50 ft east of the shelter. Ventilation from all other directions was unobstructed. The ground was generally bare in the immediate vicinity of the shelter, but there were large grassy athletic field areas to the south. The elevation was about 100 ft above sea level.

In addition to the data collected by the project personnel, data were also made available by San Jose State College and the San Jose Municipal Airport. The thermometers, anemometer, and pyrheliometer at San Jose State College are located on top of the three-story Engineering Building. The instruments are at a height of about 125 ft above sea level. The airport instruments are located in the middle of the runway complex at a height of about 8 ft above ground level or about 60 ft above sea level.

C. Albuquerque

The routes used in Albuquerque are shown in Fig. 8. Turn numbers (including some of the intermediate points used in analysis) are labeled in the figure. This figure also shows pictures of typical areas along the routes and of the hygrothermograph locations. The arrows connecting the pictures to the locations on the map indicate the approximate directions in which the camera was pointed. Figure 9 shows the topography and built-up areas (U.S. Geological Survey, 1960) of Albuquerque. Details of the routes are described in Appendix A. The elevations above sea level along the Albuquerque routes range from about 4950 feet in the areas near the Rio Grande to about 5620 feet at Turn 9 on Route 2. The topographic contours are generally aligned in a north-south direction. As one proceeds toward the west, the land generally slopes downward from the eastern edge of town, with a sharper drop into the Rio Grande Valley just east of the central part of town. The bottom of the Rio Grande Valley is relatively flat and about two to three miles wide. West of the valley bottom, the

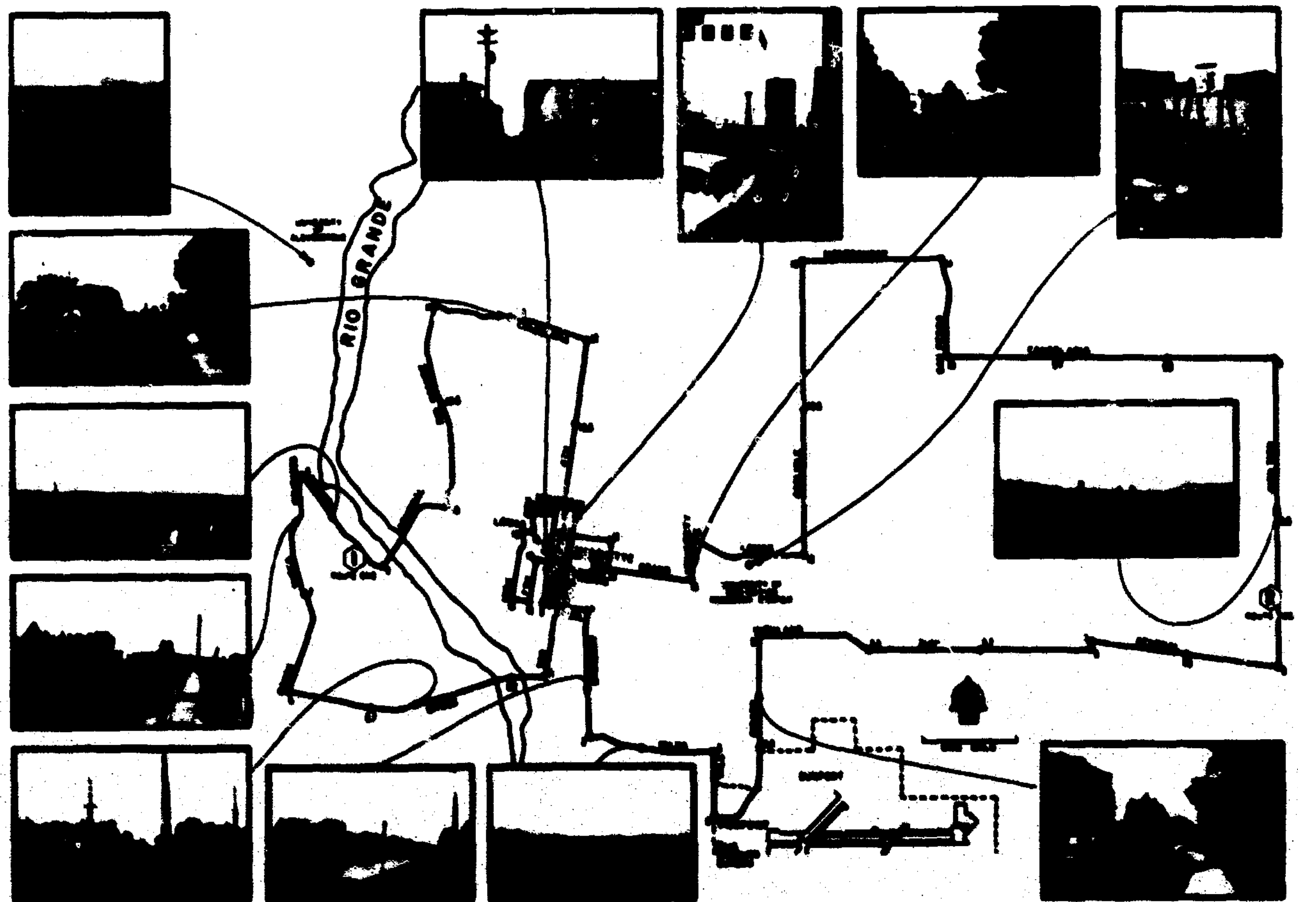
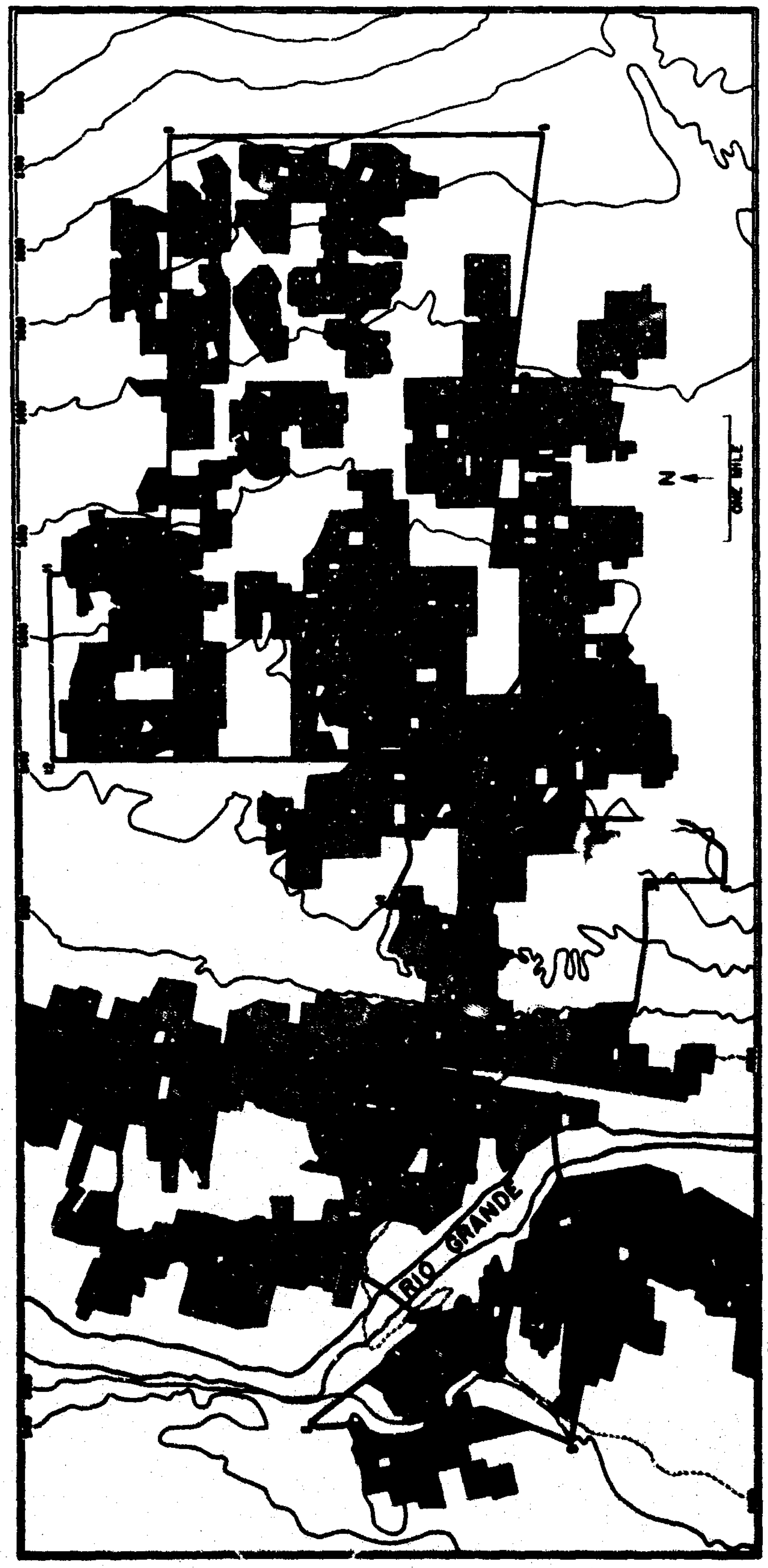



FIG. 8 ALBUQUERQUE ROUTES WITH PICTURES OF TYPICAL AREAS




U S Geological Survey, 19[illegible]

FIG. 9 ALBUQUERQUE ROUTES SHOWING TOPOGRAPHY AND BUILT-UP AREAS land rises in one fairly sharp step followed by a gradual upward slope toward the continental divide to the west.

Albuquerque has a population of about 300,000 (Rand McNally, 1966). As can be seen from Fig. 9, the area is not uniformly built up nor is it symmetrically built up with respect to the Rio Grande. The routes cover a reasonably representative portion of the city, from its eastern edge to its western edge; they also cover a variety of neighborhood types within the city boundaries. The downtown area is approximately marked by the area enclosed by 2nd, 5th, Coal, and Tijeras Streets in Fig. 8.

One hygrothermograph was located at the University of Albuquerque at the northwest corner of the city. This location is on top of a palisade overlooking the Rio Grande. The elevation is about 5120 feet. The surface in the immediate area of the instrument shelter was barren, sandy soil typical of the area. Some buildings were being constructed several hundred feet west of the shelter and there were some buildings a few hundred feet to the southwest. Instrument ventilation was good from all directions.

The other hygrothermograph was located at the University of New Mexico Research Center on Lomas Blvd. at an elevation of about 5150 feet. During the first period of operations, the instrument was located in a storage area about 50 feet west of the Research Center building. It is this location that is shown in the photograph in Fig. 8. To the south and west of the location there were large areas of barren, sandy soil; to the north was Lomas Blvd. several hundred feet away, with a vacant area in between. In the immediate vicinity a number of items were stored, including some electrical equipment. The instrument shelter was above these stored items and they did not affect its ventilation.

During the second period of operations in Albuquerque, the hygrothermograph was situated on a grassy area on the other side of the Research Center from the storage yard. The move was necessary because the storage yard had been removed to make way for grading operations in the area. The instrument was about 50 feet from the Research Center to the west and about 50 feet from a fenced backyard to the east. To the south was the open area and to the north Lomas Blvd. Ventilation from either the east or west was probably somewhat restricted, but should have been good from the north or south.

In addition to the data collected from the hygrothermographs, data were also obtained from the U.S. Weather Bureau. Their instrumentation is located at the Albuquerque Sunport (airport) at an elevation of about 5310 feet. The anemometer is about 23 feet above ground level and the pyrheliometer about 38 feet. Psychrometer measurements are taken at about 15 feet above ground level.

D. New Orleans

The routes used to survey New Orleans temperatures are shown in Fig. 10. The photographs in the figure show typical scenes at various locations on the routes. As before, each arrow points in the direction that the picture was taken. The turn numbers and some intermediate numbers used in the data analysis are shown in the figure. The details of the routes are described in Appendix A.

New Orleans is a flat city situated at sea level. The highest elevations in the city are about 20 feet, along the riverfront levees, and 5 to 10 feet, along the shores of Lake Pontchartrain and the navigation canal.

The New Orleans metropolitan area has a population of about one million (U.S. Bureau of the Census, 1966). As can be seen from Fig. 11, the southern part of the city is nearly completely covered with buildings (U.S. Geological Survey, 1951). The only major open area in the southern part of town is Audubon Park. The northern part of the city is almost evenly divided between built-up areas and open lands representing parks, cemeteries, air fields, and campuses. The downtown business area starts along Canal Street and extends several blocks to the southwest between about Tchoupitoulas and Claiborne. The French Quarter is approximately bounded by Canal, Esplanade, Rampart, and Decatur.

One of the program's hygrothermographs was loc. ed at the U.S. Department of Agriculture Regional Research Laboratory. The instrument shelter

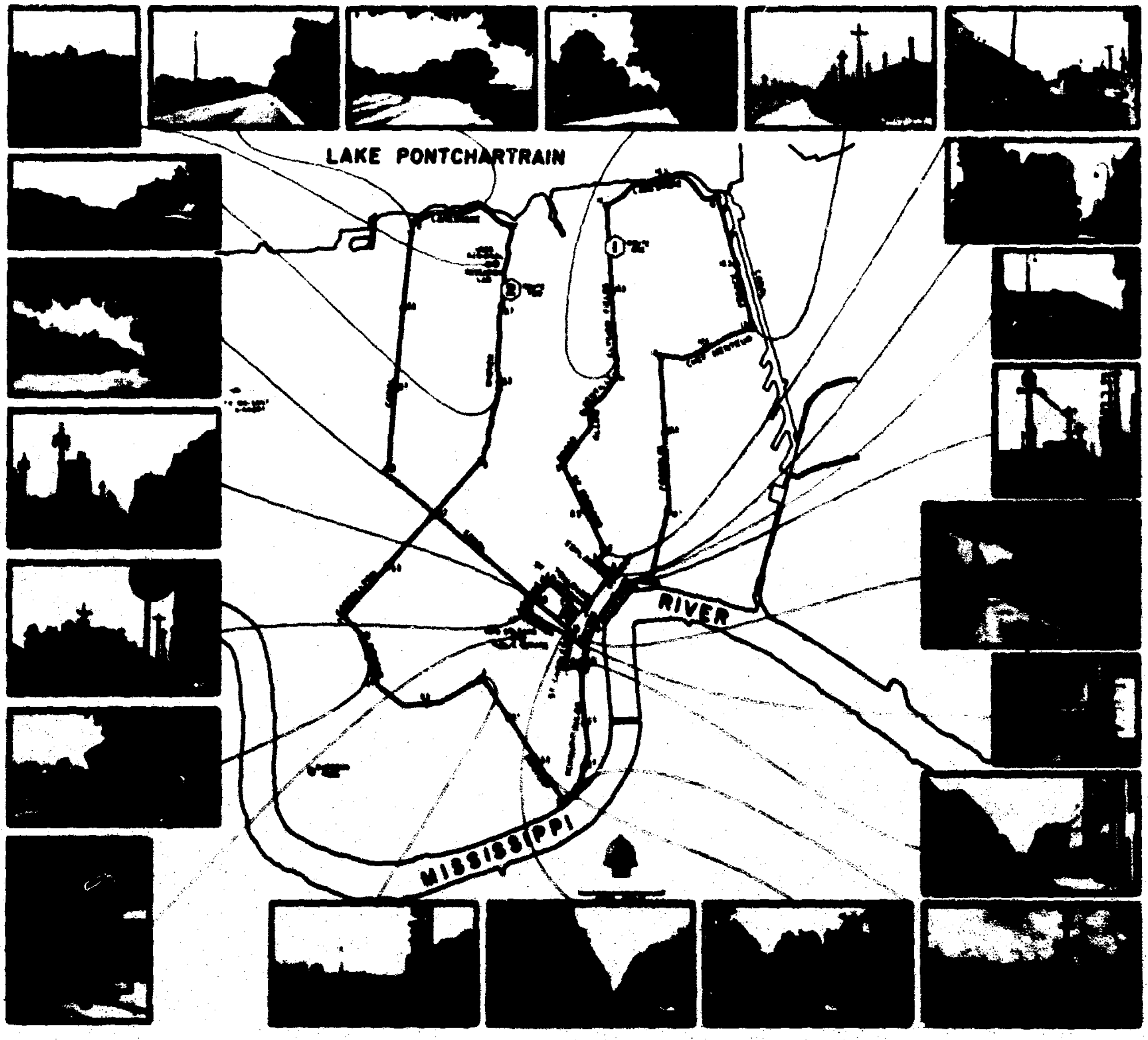



FIG. 10 NEW ORLEANS ROUTES WITH PICTURES OF TYPICAL AREAS


U.S. Geological Survey, 195?

FIG. 11 NEW ORLEANS ROUTES SHOWING BUILT-UP AREAS was placed in a large, open, lawn-covered area about 100 feet northwest of the building. There was some shrubbery and the one building in the area; otherwise the area was clear in all directions. The instrument exposure was very good at this location.

The other hygrothermograph was placed in a conventional instrument shelter on the roof of the two-story New Orleans Public Service Company building. This location is about 1/4 mile west of the downtown area. The instrument shelter was on top of a graveled asphalt roof. Exposure was good with no major impediments to airflow in any direction in the immediate vicinity. Both hygrothermograph locations are pictured in Fig. 10.

Data were also obtained from two U.S. Weather Bureau sources in the New Orleans area. One of these was located at Moisant International Airport, about 13 miles west of New Orleans. There are no land elevations above 20 feet within 50 miles of the airport. The area surrounding the airport is generally swampy except for that which has been reclaimed. Wind instruments are at a height of about 50 feet above the ground. Other measurements are taken at heights of about five or six feet.

Other available New Orleans Weather Bureau measurements are taken at the east side of Audubon Park. The readings from this site are remotely registered at the U.S. Weather Bureau Office in the Federal Building. The wind measurements are made at a height of about 20 feet above the ground, the other measurements at about 6 feet.

## IV DATA REDUCTION

In its original, raw form the data fill about 1 foot of chart paper for each recorder for each hour of operation. There were four recorders in use so there were four feet of chart for each hour and each chart contained two temperature records, wet bulb and dry bulb. During the field measurements, some of the upper dry bulb temperatures were read directly from the charts and graphically interpolated to give synoptic charts of the distribution of this one element over the city. From this experience, it became evident that such an approach would be inefficient and unsuitable for the treatment of the total mass of data which we had collected. It was decided to put the data on punched cards so that the interpolation and other mathematical manipulations could be performed by computer. This section describes the methods used to put the data on cards, sort it, edit it, and perform some of the initial interpolation and averaging.

### A. Transfer to Punched Cards

The first step in any scheme for the manipulation of chart records by a digital computer is to get the data into digital form. There are devices which automatically convert linear distances to numbers and punch these numbers on cards. One such device, Oscar Model J,* was used to convert our chart readings to punch card form. The Oscar readings are a measure of the position of the temperature graph, not the actual temperature. To determine the actual temperature from an Oscar reading, it is necessary to know the Oscar readings corresponding to two given temperatures. Then the actual temperature can be determined from the Oscar reading by linear interpolation, that is, if the temperature is a linear function of the position of the temperature trace. The

* Benson-Lehner Corporation 14761 Calif. St., Van Nuys, Calif.



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assumption of linearity is not quite true over the entire span of the chart paper used with the Rustrak recorder, but is more than accurate enough (when compared with instrumental accuracies) to be used over spans corresponding to about 5°C. The Oscar punches a three-digit number corresponding to its position. As used in this program, a change of one in the Oscar reading corresponds to a change in temperature of about 0.02°C. This precision was more than adequate to define temperatures well within the accuracy limits with which they were originally measured.

It takes five numbers to define an actual temperature: one Oscar reading corresponds to the temperature read from the chart, and two pairs of Oscar reading and temperature are necessary to provide the information for interpolation. In addition to the temperature information, there must also be information defining the location, the date, the time, and the type of temperature (e.g., upper wet bulb, lower dry bulb, etc.).

The card format used is as follows: The first twelve columns are left blank to accommodate any information which we may want to add later. Columns 13 through 17 specify the date. Columns 19 through 21 indicate the city, the route number, and the type of temperature (top dry, top wet, bottom dry, and bottom wet). Columns 23 through 26 indicate the turn number with decimal and tenths to use for cases where readings were interpolated between turns. In columns 28 through 31, time is recorded to the nearest tenth of an hour. Columns 33 through 35 receive the three digits of the Oscar reading corresponding to the temperature. The fields comprising columns 37 through 39 and 41 through 43 gave, respectively, a temperature (in tenths of a degree Celsius) and the corresponding Oscar reading. The second interpolation temperature was given in columns 45 through 47 with its corresponding Oscar reading in columns 49 through 51.

Prior to the actual punching of the data on cards, the records were prepared. Times were converted from the hours and minutes recorded in the field to tenths of an hour and marked on the chart at the proper places. Some preselected points, intermediate to the regular turns (see maps in Section III), were interpolated by eye and marked on the chart with the time estimated for the point. The curves were smoothed out somewhat to eliminate the short period fluctuations which corresponded to a size scale too small to be significant to the type of analysis planned. This smoothing was also used to eliminate large, unrepresentative temperature rises which sometimes occurred at the lower sensing level during times when the vehicle was stopped in traffic. These arose from warm air from the engine or from the exhausts of other vehicles being wafted to the lower sensors. This phenomenon was observed often in the field and we do not feel the temperatures measured under these conditions were representative. This phenomenon was almost never observed with the upper sensors which were above the level where they would be affected by exhaust fumes or warm air from around the engine.

B. Editing and Sorting the Data

Approximately 35 to 40 thousand cards were punched. With such a large number of cards it was necessary to develop a machine method of checking for errors and for organizing the data into a form suitable for all foreseeable operations which might subsequently be desired. This section describes the approach developed for this purpose by Vincent Lauricello, SRI, Mathematical Sciences Group.

Figure 12 shows a flow chart of the editing and sorting program used to process and consolidate the data. As can be seen from the figure, the punched card data are transferred to magnetic tape. The data from each city are put on an individual tape and processed separately. The tape is read by the computer and subjected to a sorting routine (labeled ASG-1). The first function of this routine is to count the number of entries for each date. Each date that has less then 400 items or more then 1500 items is listed. This helps to determine whether or not some data have been lost or if, there is too much data for one date.

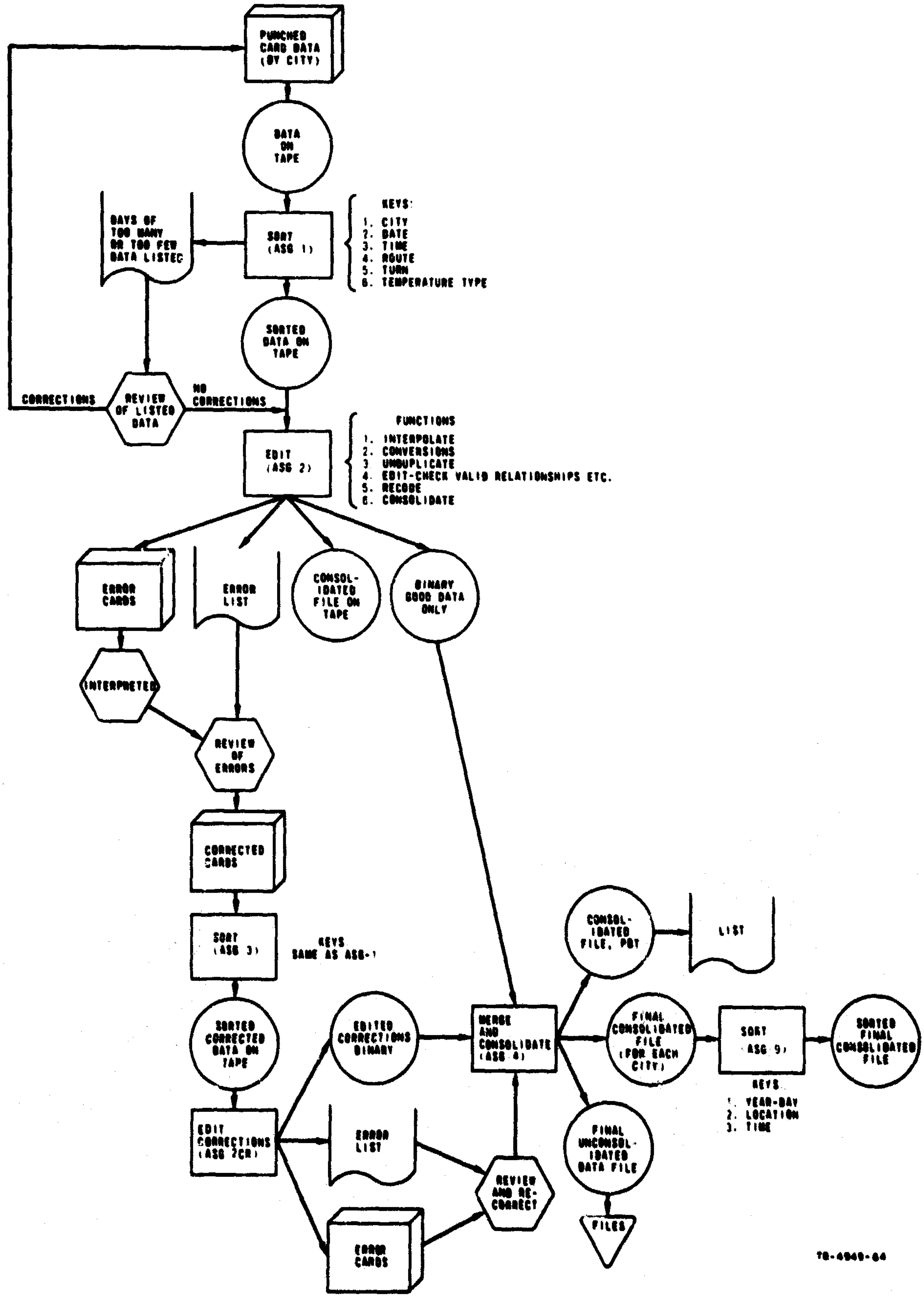


FIG. 12 FLOW CHART FOR DATA EDITING AND SORTING PROGRAM

The sorting routine continues, arranging the data according to date. Then, within each date, the data are ordered according to time. The data in each time grouping are ordered by route and turn number. The final sort in this routine is according to the temperature type.

If any errors are identified among days which have too many or too few data, they are corrected and the data are resorted. The sorted data are recorded on magnetic tape, which is used as an input to the edit routine (ASG-2). A number of rules for the acceptance of the data were selected. The edit routine applies these rules and rejects data which do not fall within the specified bounds. This routine also determines the actual temperature from the interpolation points and the Oscar reading. The routine consolidates the data; in the consolidated form, all four types of temperature are listed, together with the appropriate city, date, time, route, and turn information. In this form the number of listings of the corollary information is reduced by a factor of four.

The rules used to check the data are listed below. The order in which these rules are presented is the order in which they were applied. First the data are checked for duplications of the following: city, date, time, route, turn, and type of temperature. Both items in a duplicate pair are rejected. Each remaining record is then checked to determine if the number specifying the city is one of those that has been assigned. Then the data are checked to determine if the day specified is one during which observations were made in that particular city. Next, the time is checked to determine if it falls within the observation intervals for that particular day. The next check rejects any cards which might have route numbers other than route one or two. Then the turn number is checked to see if it is one of those specified for the particular city and route. Next the temperature type is checked to make sure it has a legitimate code.

After all the corollary information has been checked for validity, the temperature is calculated from the Oscar reading and the interpolation numbers. Further checks are performed at this time. The straight line used to determine the temperature from the Oscar reading is checked to make sure that its slope falls within certain limits. Finally the interpolated temperature is examined to make sure that it is between 5°C and 45°C.

After all the data are checked according to the rules outlined above, the rejected data are reproduced in two forms. A set of cards is punched in the format of the original data. These punched cards are then interpreted, i.e., the characters corresponding to the punched holes are printed across the top of the card. The rejected data are also reproduced in the form of a list. The rule by which each piece of data was rejected is identified in this list.

The list of errors and the corresponding cards are examined by the researcher. Some cards are discarded and others are corrected. The corrected cards are then sorted by routine ASG-3. This sorting is done to the same order as was done by routine ASG-1. The sorted, corrected data are then reedited. If there are still errors, they are listed as before for examination and recorrection.

The data which are accepted by the original editing routine are reproduced on magnetic tape in binary form. This tape, plus the tape from the correction process are introduced into a merge and consolidation routine (ASG-4). The data files are consolidated to form one complete, ordered file. Where corrections have been made to data which had originally been accepted by the editing routine,* the corrections replace the original data in the composite file.

There are three outputs from the merge and consolidate routine. One of these is a magnetic tape record of the consolidated, corrected data for one city. This is a printer backup tape which can be used to produce printed lists and serves as a second data source in case of mishap to the primary output. Another output of the merge and consolidated routine is a tape record of unconsolidated data. This corresponds to the

* This can occur when an entire route has been punched with the wrong number (1 instead of 2 or vice versa). This error shows up as a series of unacceptable turn numbers. The whole route is replaced, including the records not originally rejected by the editing.

output of the first sort routine (ASG-1) except that the data have been edited, the errors have been corrected, and the temperatures have been calculated from the Oscar readings. The third output of the merge and consolidate routine is the most important to subsequent operations. It is a tape record of the consolidated file, which has been resorted to an order more suitable for the necessary curve fitting operations. In this final sorting routine (ASG-9) the data are grouped first by date, then by route and turn numbers, then by time of day. This order is necessary for the interpolation and averaging routine which is described in the following section.

C. Interpolating and Averaging The Data

The sorted, consolidated file, is the end product of the editing process described in the previous section. It is the data source for the interpolating and averaging routine described in this section. The flow chart for the interpolating and averaging routine is shown in Fig. 13. The records are processed by the computer one at a time and in the serial order in which they have been entered on the tape. The incoming record is tested to determine if it is the first daytime record. If it is, its date and location are entered in test 4. This test will be discussed later. Of course, only the first daytime record will take the route just described; the others will pass directly to test 2, leaving test 4 unaffected.

Test 2 determines if the record passing through is the last record. If it is, averages are computed and listed. The averaging process will be discussed in more detail later. When the record is not the last of the file, it passes to test 3, which determines if it is a day or night record. Daytime records have been defined as those collected between 0800 and 1700. The others, nighttime records, are not to be averaged and are disregarded in this program. When a night record is encountered, test 3 causes processing to cease on that record, and the program passes to the next record in the file.

Processing continues for daytime records which pass to test 4. Test 4 contains a date, route, and turn number against which the incoming

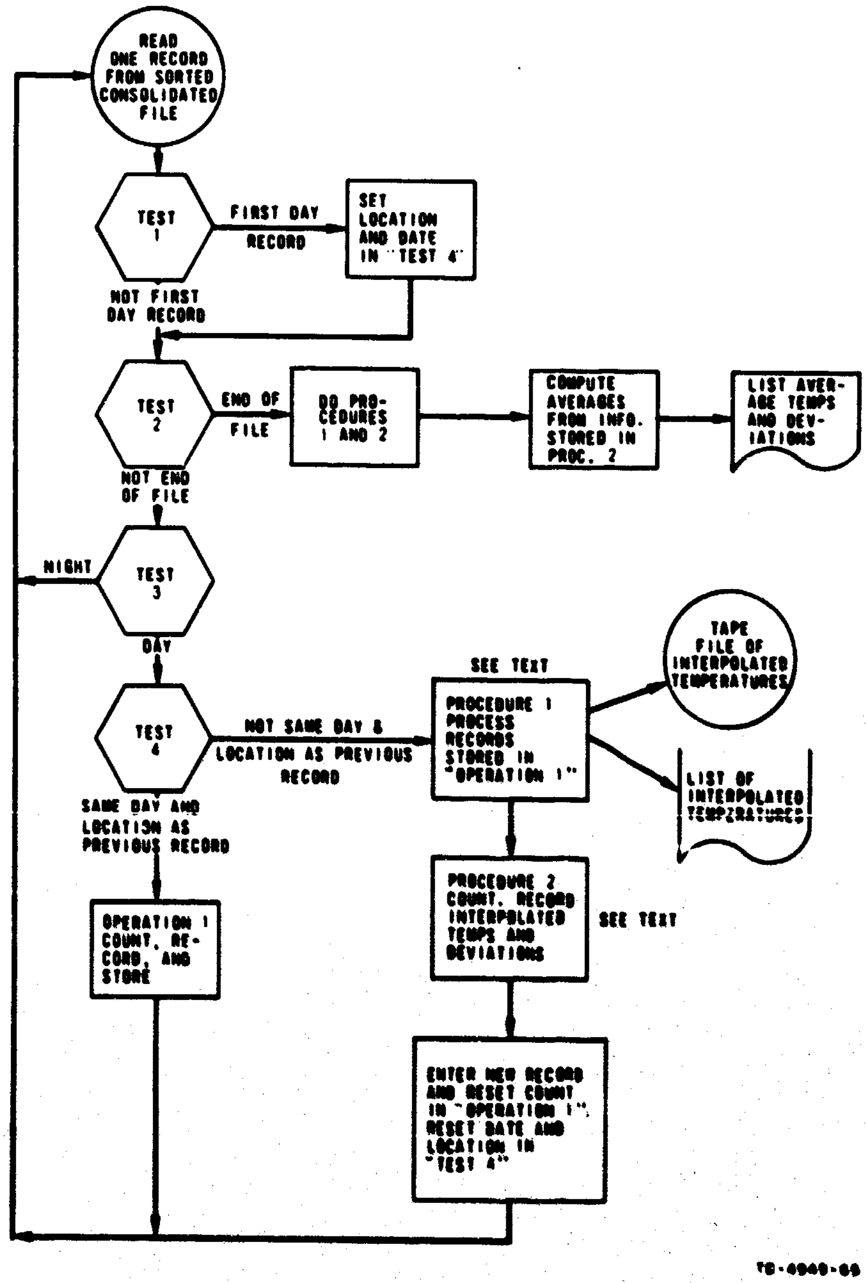


FIG. 13 FLOW CHART FOR INTERPOLATION AND AVERAGING PROGRAM

record is to be checked. If the record passing through test 4 has the same date, route and turn number as is currently recorded, then it is counted, stored, and a new record is read. Because the input tape is ordered such that all data for a given date and location are recorded serially, the program will store all the data for a given date and place, before it begins to process it further. When a record with a new date or location reaches test 4, it is a signal for the stored data to be processed. This processing (procedure 1 in the diagram) will be discussed in more detail later, but for now it is sufficient to say that a curve is fitted to the points and this curve is used to determine the values of temperatures at integral hours over the day. These interpolated values are listed, and entered on a tape file. They are also entered into procedure 2 where each type of temperature is sorted according to time and location, counted, and then added to the sum of the values which have previously been entered in the space allotted to that same hour of the day, temperature type, and location.

After the data stored in "Operation 1" have been processed according to procedures 1 and 2, the processed data are erased from storage and the record which triggered the processing is counted and recorded in operation 1. Also, the date and location of this record replaces the date and location which had been used in test 4. The next record is then read and starts its way through the routine.

Returning to procedure 1, the primary function of this procedure is to determine interpolated temperatures at specified times, i.e., integral hours. This is done by fitting a curve to the observed time-temperature points, and then, from that curve, calculating the temperatures at the desired times. The nature of the curve will depend on the number, and spacing in time, of the observations. If only two observations are available, a straight line is used; if three are available a quadratic is fitted. When four or more points are available, they are fitted with a series of quadratics. The first three points are fitted with a quadratic, then the three points beginning with the second point are fitted and so on to the last three points. The quadratic chosen to calculate the interpolated value of temperature depends on the time for which the value is to be calculated. Obviously, when the time for which the interpolation is desired lies between the first two points the quadratic fitting the first three points will be used. Similarly, a point between the last two observations will be determined from the quadratic fitting the last three observations. For other cases, the observation closest in time will be the middle point of the quadratic used for interpolation. Extrapolation beyond the endpoints is carried out if the time is within 3/4 hour of the endpoint.

When all the interpolated temperatures have been calculated, deviations from a standard temperature are determined. For the dry-bulb temperatures the reference is the dry-bulb temperature observed at the airport at local noon of the same date: for wet bulb temperatures it is the noon, airport wet-bulb temperature. The proper reference temperature is subtracted from each interpolated temperature.

Earlier in the discussion it was mentioned that the interpolated values of temperature are added to the sums of other interpolated temperatures of the same type, the same location, and the same time of day. This is done as part of procedure 2; this same procedure also records running sums of the deviations in the same fashion. These sums and the total number of items summed in each group are used to compute the averages at the end of the program. Returning to test 2 in Fig. 13, it can be seen that the last card causes the final interpolated temperatures to be calculated and added to the sums in procedure 2. These sums are then converted into averages and the averages are listed.

It has already been mentioned that test 3 causes the routine to skip the nighttime test data. The nighttime data are processed separately because they are not to be averaged. The program by which the night data are interpolated is quite similar to the one outlined in Fig. 13. Among the differences are the following: first, averages are not calculated at the end of the file, and second, test 3 skips daytime data and processes only nighttime data. The output of the nighttime data processing program is a list of interpolated temperatures similar to the list of interpolated temperatures produced for daytime data. However, the nighttime list does not include average values of the temperatures or averages of the deviations from noon temperatures.

## V RESULTS

### A. General

The analysis of the data is still in a preliminary stage, but there are some interesting results which can be displayed. The graphical presentation of the data takes two forms in this section. The first of these forms displays the distribution of temperature over the area of the city. Two-meter and 0.3-meter temperatures and wet and dry bulb temperatures are presented in this way. Maps of 2-meter and 0.3-meter temperatures are given for each of several hours of the day. The second method of presentation consists of graphs of temperature versus time for several types of locations within each city. In this case the graphs have been confined to the 2-meter dry bulb temperatures.

These preliminary results are confined to averages partly because the averages reflect many of the features found in individual cases and partly because analysis of individual cases in terms of prevailing meteorological conditions has not been completed. The determination of averages presents some problems. First, operations were not conducted over the same time periods every day so that specific days which compose an average in the afternoon may be different than the days used for a morning average. If the number of cases involved is large, this may not be a serious problem. However, in this program, the number of available daytime samples was generally of the order of ten.

To suppress the effects of the day-to-day changes in the absolute values of the temperatures without masking temperature gradients or rates of change of temperatures, we chose to average relative temperatures. This has already been mentioned in Section IV. Each of the absolute values of the temperatures has subtracted from it the temperature observed at noon of the same day at the local airport. Airport dry bulb temperatures are subtracted from dry bulb temperatures and airport wet bulb temperatures from wet bulb. The differences are then averaged.



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By using these relative temperatures, averages can be calculated and used to illustrate average gradients and rates of change without attributing undue significance to absolute values of the averages.

There are problems and anomalies which arise in spite of the relative averaging which we have used. These will be discussed in more detail later in this section. It is sufficient to note here that the most serious anomalies arise in connection with very local phenomena such as thundershowers, which can cause large temperature changes over a relatively small area. Although we are aware of these anomalies in many cases, the analyses have been carried out for the averages as calculated. We have not yet attempted any corrections or compensations.

The relative wet bulb temperature averages do not lend themselves at all well to analysis of the humidity fields. They are shown because they do give some qualitative concept of the nature of the variations in these fields. Although this variable is adequate for these preliminary analyses, it is apparent that better choices can be made for future, more detailed work. Because of the shortcomings, inherent in the use of this variable, the discussions of humidity which follow will be limited.

Before proceeding to a discussion of the data, one more characteristic of the following analyses should be mentioned. It will be noted that there appear to be fewer small-scale features of the temperature fields in the outlying areas of the cities than in the downtown areas. This may be the result of the nature of the routes used for the temperature measurements. Generally, the spacing between data points is greater in the outlying areas than it is in the downtown areas. Thus the small features of the temperature fields may be undetected in the wider spacing between data points in the suburbs. To some extent this is ameliorated by the generally greater size of homogeneous residential districts in the surrounding areas.

## B. San Jose

The average deviations from 1200 Local Standard Time airport temperatures in San Jose are shown in Fig. 14. Table II shows the average deviation of San Jose airport temperature from its own noon value for various hours of the day. These averages are for the days of daytime operations shown in Table I. Also given are the averages of the hourly temperatures during days of operation.

Table II

HOURLY AVERAGES OF SAN JOSE AIRPORT TEMPERATURES AND AVERAGE DEVIATIONS FROM NOON VALUES FOR DAYS OF OPERATION

| | Local Standard Time | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 |
| Average Temperature (°C) | 16.9 | 19.0 | 20.9 | 22.5 | 24.4 | 25.3 | 25.6 | 25.1 |
| Average Deviation from 1200 (°C) | -7.5 | -5.4 | -3.5 | -1.9 | 0 | +0.9 | +1.2 | +0.7 |

By comparing the maps for the upper level (2-meter) temperatures with those for the lower level (0.3-meter), it can be seen that temperatures at lower levels generally average between 1 and 2°C greater than those at upper levels. The average difference between the upper and lower wet bulb temperatures is somewhat smaller than average difference between the dry bulb temperatures.

A feature common to nearly all the fields shown in Fig. 14 is their flatness. There are no great changes in the average temperatures from one part of a map to another. This is particularly true of the wet bulb temperature fields where there is seldom a variation of more than 1°C over the entire area covered. For isotherms drawn at 1°C intervals, there are several cases where all the lines represent the same wet bulb temperature, e.g., 1100 and 1300 at both levels, and in other cases hardly any wet bulb isotherms appear at all, e.g., 0900 and 1000 for the lower element. There is one case where a large gradient of wet bulb temperature occurs, the 2-meter 0900 temperature field. Even in this case though, the difference between the greatest and smallest wet bulb temperatures in the entire area is only about 2°C.

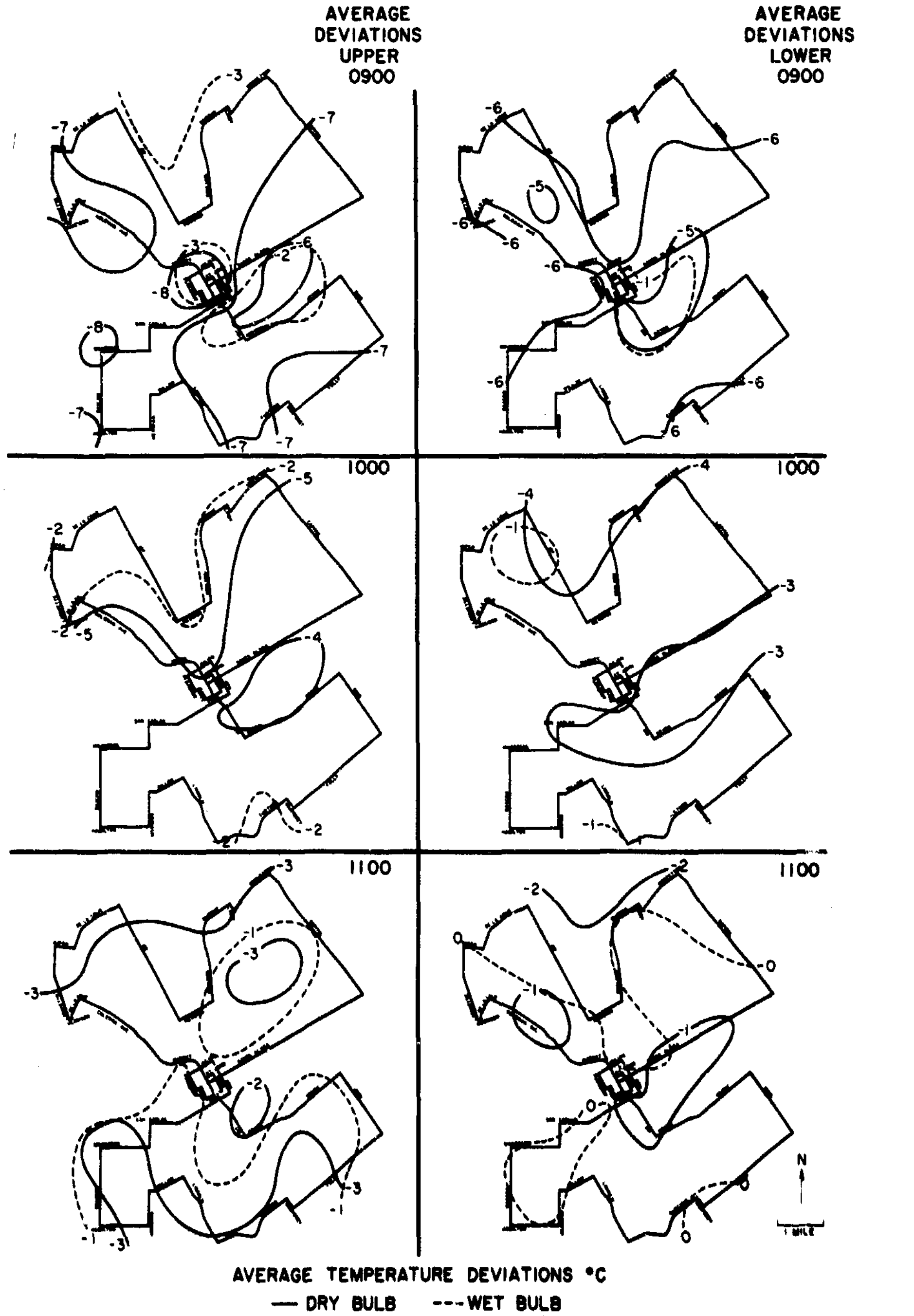



FIG. 14 AVERAGE RELATIVE WET AND DRY BULB TEMPERATURE FIELDS FOR SAN JOSE

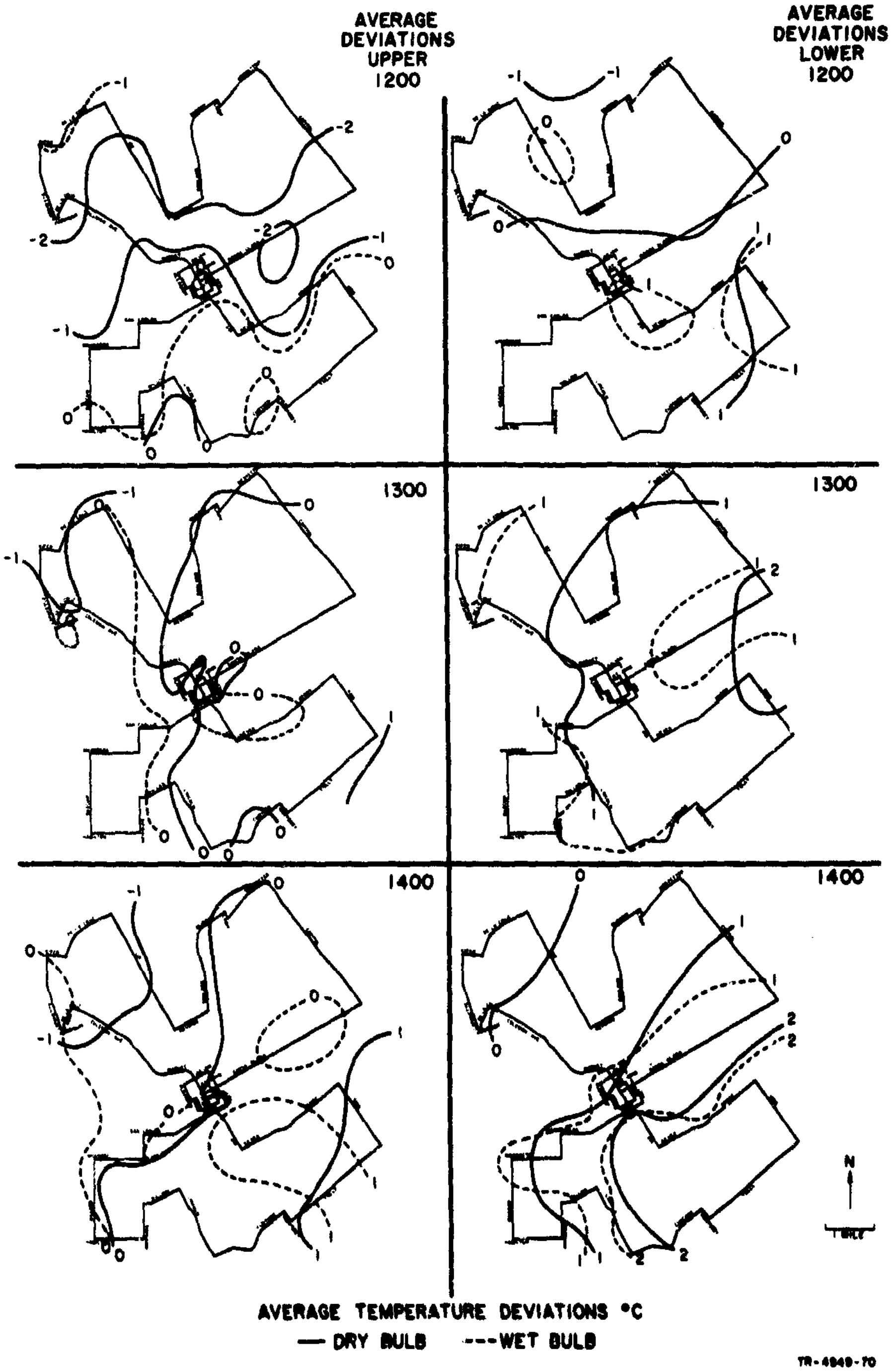



FIG. 14 Concluded

The average dry bulb temperature fields are not so flat as are the wet bulb fields, but nevertheless there are only a few large gradients. The largest average horizontal gradient, about $4^{0}$C/mile, occurs just at the southeastern edge of the downtown area at 0900. According to the analysis, the difference between the highest and lowest average 0900 temperatures in the San Jose area is only about $3^{0}$C. Similar differences are observed in the afternoon at 1400. However, in the afternoon the extremes are located at opposite corners of the map, while the 0900 case has the extremes within two miles of each other.

It appears that the mechanisms involved in the two cases cited above are different. It can be seen that a reasonably well organized pattern develops in the dry bulb temperature field at about 1200. The last three hours shown in Fig. 14 give very clear evidence of a gradual increase in temperature from the northwest to the southeast. This undoubtedly is in response to San Francisco Bay, which lies to the northwest of San Jose. Although morning winds were generally light and variable during the observation period, afternoon winds were almost always from the quadrant between west and north, and the wind speed often increased significantly about midday.

It appears from the nature of the 2-meter dry bulb temperature fields that geographical influences dominate the observed average patterns in San Jose in the afternoon. There is some distortion of the isotherms in the downtown area, but generally the downtown temperatures are not much different from the immediate surroundings. However, at 0900 the situation is different; the heart of the city is more than a degree cooler than the surroundings. By 1000 the city center is no longer appreciably cooler than its surroundings, although a north-south trough in the temperature field does pass through the downtown area. The warmer area east of the business district can still be seen at 1000. The intensity of this warm center decreases by 1100. At 1100 the field is nearly flat, a little cooler at the northern and southern edges of town, a little warmer along the band between. By noon the dominance of geographical controls has begun; the general trend is for the air to become warmer toward the southeast. However, there is some evidence that the downtown area and the area just to the east of it have a temperature relationship which is the reverse of what was observed earlier in the day. The town center is now warmer than its surroundings and the area to the east of it is cooler. By 1300 the effects of the city have nearly been erased by the breeze from the Bay.

If the downtown area of San Jose has an effect on the temperature distribution within the area, this effect is displaced from the downtown center. The displacement, which is possibly the result of advection, is generally toward the east or southeast of the downtown center. The warm area, which is about 1/2$^{o}$C warmer then the surroundings, is plainly evident to the southeast of town in the 1000 and 1100 temperature fields. The effect diminishes in the afternoon.

The general features of the 2-meter field are strongly reflected in the 0.3-meter temperature field; it would be quite surprising if it were otherwise. However, the gradients and features of the 0.3-meter average temperature field are not so pronounced as are those of the 2-meter field. This may have arisen because of the necessity for greater smoothing of the data from this level (see Section IV-A).

As mentioned, the wet bulb temperature field is relatively flat; but what features there are, tend to coincide with the highs and lows of the average dry bulb temperature field.

Inspection of the wet bulb fields shows that the variations in absolute humidity are too small to be interpreted in a subjective manner, and an intelligible presentation will require the calculation of dew points or mixing ratios at some future time.

All the individual 2-meter dry bulb temperature fields have been analyzed and many of the features of the averages can often be identified in the individual cases. Although no individual day is exactly like the average, the average does have enough features in common with enough individual cases that it serves very well as a representation of a "typical" case.

One comment needs to be made concerning the 2-meter average 1200 dry bulb temperature deviation that is indicated for the airport. If the airport 1200 temperatures, which were used as reference temperatures in calculating the deviations, were representative of the surroundings, the $0^{o}C$ average temperature deviation isotherm should pass through the airport location on the 1200 map. From the fact that the isotherm field shows a deviation of about $-1.8^{o}C$ in this area, it appears that the measured temperature at the airport is 1 to $2^{o}C$ too warm at noon, on the average. Differences of the same sign and about the same magnitude are observed at the other hours shown in Table II and in Fig. 14. Because of the instrument's location in the runway area, radiation errors might account for this difference.

Temperature measurements were made during two September nights in San Jose. Preliminary analyses indicate that as the night progresses the downtown area becomes significantly warmer than its surroundings. Nighttime gradients are considerably larger than those observed during the day. Differences of several degrees Celsius have been observed at night between different locations in the area.

Figure 15 shows the average change of 2-meter dry bulb temperatures with time of day for several types of neighborhoods in the San Jose area. Each curve is identified by a hyphenated number representing a location. The first number identifies the route and the second, the turn number (see Fig. 6). The curve marked zero is for the corner of Santa Clara and Market, the start and end of both routes.

Although most of the curves in Fig. 15 extend beyond the time when the maximum temperature occurs, it would be desirable if they extended farther. These curves are averages of interpolated values and many of the data for individual days and locations do extend farther beyond the time of maximum temperature. Because of differences in the times of the last measurements between the beginning and end of routes and differences in the time of occurrence of maximum temperatures, it will be necessary to study the individual data to gain the full benefit of the available post-maximum measurements. Similar treatment is needed for the data from the other cities.

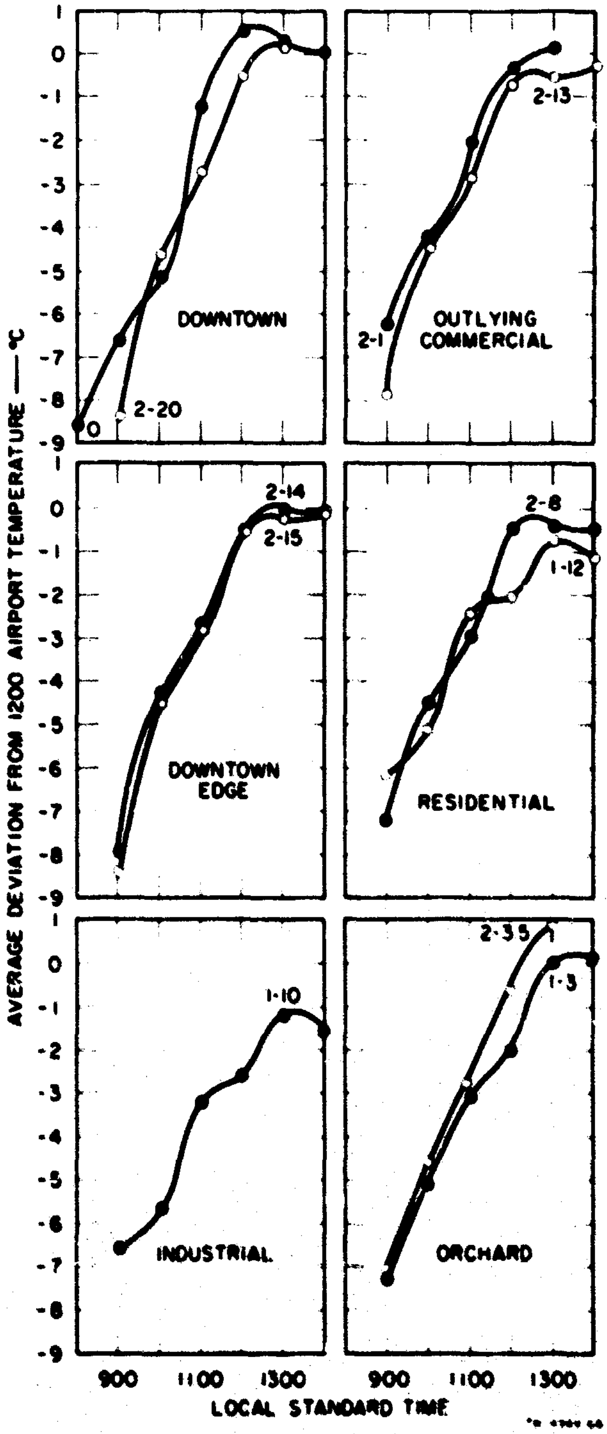



FIG. 15 CHANGES WITH TIME OF DAY OF AVERAGE RELATIVE DRY BULB TEMPERATURE FOR SEVERAL TYPES OF NEIGHBORHOODS IN SAN JOSE

It can be seen from the graphs that the largest range of temperature for the hours covered by the data is exhibited by the downtown area. The range downtown, and at the edge of the downtown area, is about 8°C. This value is approached in the orchard areas surrounding the city. The outlying commercial areas have a range of somewhat less, about 7°C. These are followed by the residential areas with about 6°C range of hourly average temperature between 0900 and 1400. The industrial area, which has much open area intermixed and nearby, has the lowest range for the period studied.

The time of occurrence of maximum temperatures is not clearly defined by the averages of Fig. 15, but it appears to be earliest in the downtown area. The maximum then seems to follow in the residential areas, the outlying commercial areas, the industrial and orchard areas, in about that order. It may be more profitable to study individual cases rather than the averages for this information, which relates to the thermal properties of the different types of areas.

The weather during the field measurements reported on in this section was generally very good. The cloud cover was very rarely greater than about 3/10. No rain occurred and heavy haze was only reported a few times. The weather was generally the same on most of the days.

## C. Albuquerque

The average deviations from 1200 Local Standard Time (LST) airport temperatures in Albuquerque are shown in Fig. 16. The averages of hourly airport temperatures and their deviations from mean observations are presented in Table III. These averages are for the periods of daytime operations shown in Table I. Although the features displayed for the average temperature fields are more pronounced for Albuquerque than for San Jose, they are still relatively flat and generally without large horizontal gradients. Gradients of about 4°C/mile in the average dry bulb temperature occur at 1500 over the Rio Grande and gradients of about the same magnitude occur at 1400 for the wet bulb temperature average at the 0.3-meter level in the downtown area.

Table III

HOURLY AVERAGES OF ALBUQUERQUE AIRPORT TEMPERATURES AND AVERAGE DEVIATIONS FROM NOON VALUES FOR DAYS OF OPERATION

| | Local Standard Time | | | | |
|---|---|---|---|---|---|
| | 1100 | 1200 | 1300 | 1400 | 1500 |
| Average Temperature (°C) | 27.4 | 28.8 | 29.6 | 30.3 | 29.8 |
| Average Deviation from 1200 (°C) | -1.4 | 0 | +0.8 | +1.5 | +1.0 |

Generally the average temperature is one to two degrees warmer at the 0.3-meter level in Albuquerque--just as in San Jose. However, there are some places in the western third of the area studied where this vertical gradient is reversed at 1400 and 1500.

One of the features that is common to all the average dry bulb temperature fields displayed in Fig. 16 is the similarity of the isotherms to the topographic contour lines (see Fig. 9). The coolest place on each map is along the eastern edge and quite often at or near the northeastern corner, the highest point on the routes. Generally, the warmest parts of the field are displaced eastward from the lowest elevations along the Rio Grande. The warmest areas generally lie along a north-south line passing through the center of the city. The plateau where the airport is located is mirrored in the isotherms, although less strongly than the gradual rise toward the east.

As with San Jose, it is evident that one of the prime influences on temperature variations through the city is the geography of the area. In the case of San Jose, the principal effect is from San Francisco Bay. For Albuquerque, changes of elevation exert the most marked influence on the isotherm field. The topographic effects in the temperature field can be seen in all the maps shown in Fig. 16, not just the afternoon ones as was true of the Bay effects in San Jose.

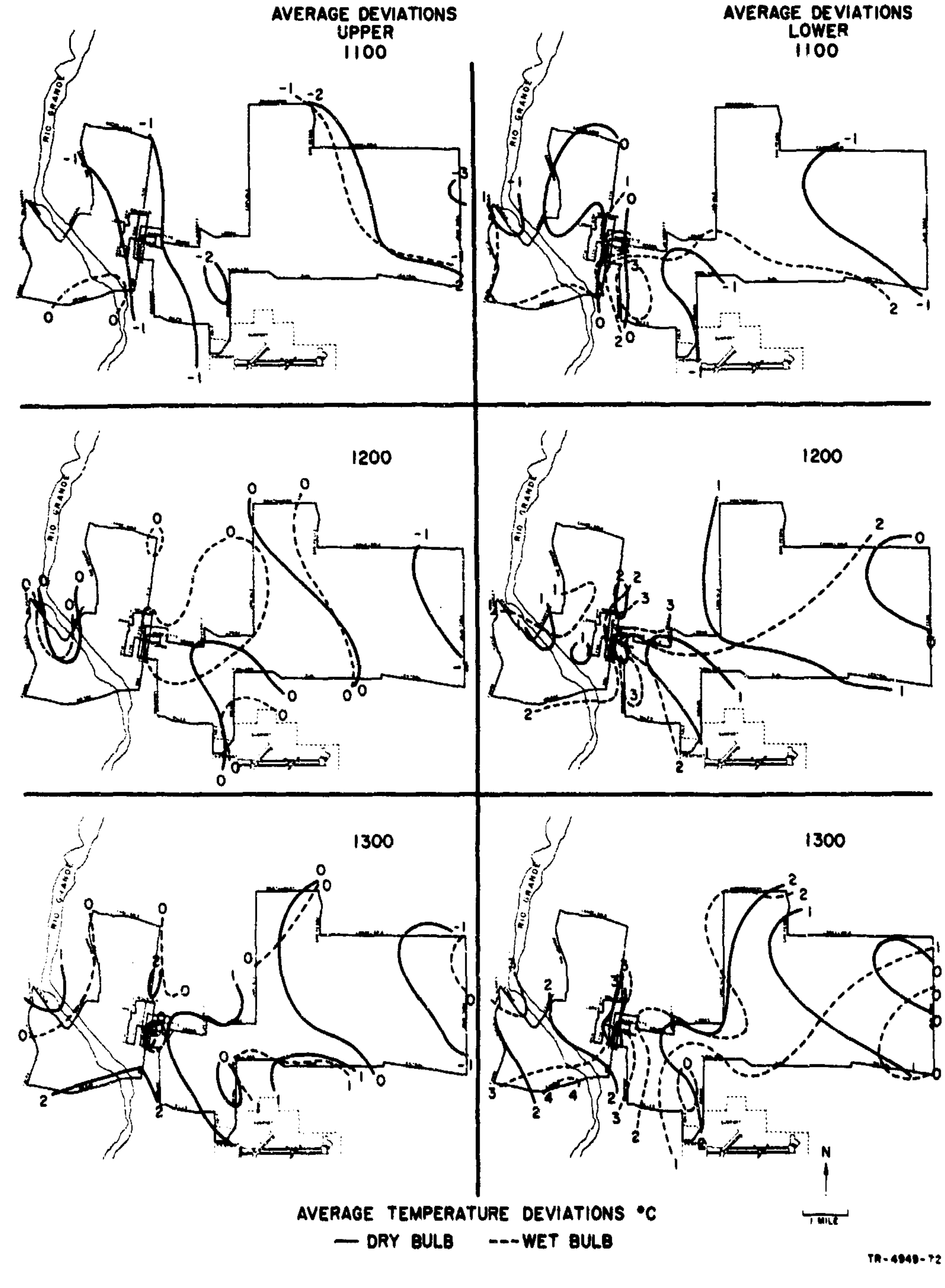



FIG. 16 AVERAGE RELATIVE WET AND DRY BULB TEMPERATURE FIELDS FOR ALBUQUERQUE

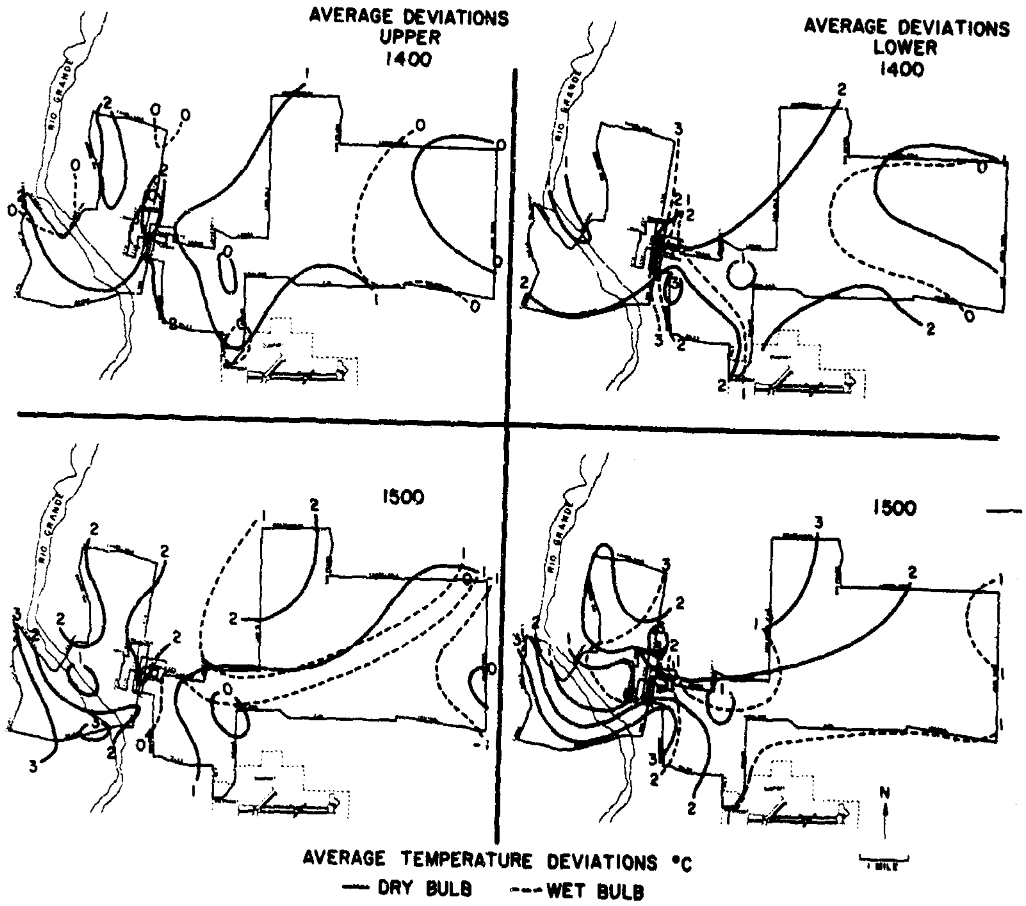



FIG. 16 Concluded

The average temperature fields give strong indications that there are influences on temperature which can be attributed to the effects of the city. The displacement of the warmest areas in the city away from the lowest elevations and into the central city is a consistent feature of those fields. Generally, the downtown area is about 1/2$^{o}$C warmer then the immediate surroundings. The area just west of the downtown area has, for all cases shown, a lower average temperature than the downtown area, although the elevations are virtually identical. This cooler area is an older residential neighborhood with many trees. Another cool pocket can be seen consistently in the area northwest of the airport. In the later afternoon this area is as cool as the areas on the eastern edge of the city, although the eastern edge is 400-500 feet higher in elevation. This cool area is another region of many mature trees.

Another feature of the temperature fields that appears fairly consistently in the averages is the trough in the temperature field which is usually aligned along the bottom lands of the Rio Grande. This feature is not as pronounced as some of those already mentioned, but this may be because no temperatures were actually measured on the bottom lands, but rather on a bridge above them.

In most cases the 2-meter and the 0.3-meter average dry bulb temperature fields are quite similar, and so the above discussion can be considered to apply to both levels. Of course there are the differences in magnitude which have already been mentioned, but the shapes of the fields correspond very well. The average wet bulb temperature fields in Albuquerque generally show greater variations than those found in San Jose. However, because of previously mentioned difficulties in the interpretation of wet bulb temperatures, the discussion of humidity fields in Albuquerque will be deferred to a later report when the data is converted to a more manageable form, such as values of partial pressure of water vapor.

All the pronounced features of the average dry bulb temperature fields can be found in the majority of the individual 2-meter dry bulb temperature fields. These fields show the cool area northwest of the airport, and the north-south warm strip running through the downtown area. The dip in temperature along the Rio Grande can generally be found and the temperature just west of the city center is usually cooler than that found downtown.

There are several cases where the usual features are not evident, but these are generally associated with thunderstorm occurrences. A thunderstorm introduces severe distortions in the isotherm field because it often brings large quantities of substantially cooler air into the area below the cloud (see for example, Battan, 1964). In the Albuquerque area, this cooler air was by no means evenly distributed. Strong horizontal gradients developed, which masked the commonly observed features of the temperature field. A storm on the afternoon of July 16, 1966, produced a difference in temperature of almost 13°C between the airport and the northern edge of the downtown area, just 3-1/2 miles apart.

Observations were made in the evening or early morning hours on four occasions in Albuquerque. These observations show temperature patterns that are similar to those observed during the daytime. The downtown area is warmer at these times than the surrounding areas, sometimes more pronouncedly so than during the day. The area northwest of the airport generally remains cool in these night cases, as does the weak temperature trough along the Rio Grande. Three of the four nights when temperatures were measured in Albuquerque were not clear. It rained on two nights, and winds of 20 knots were encountered on the one clear night. Thus, the observations which were made certainly do not represent the conditions on clear, calm nights when the effects of the city would be expected to be the most pronounced.

The changes during the day of the average 2-meter dry bulb temperature deviation are shown in Fig. 17. These graphs cover a different period of the day than did those from San Jose, due to differences in the operating schedule at the two places. For this reason, the range of temperatures in Albuquerque at first appears, to be much less than in San Jose. In fact, based on the same period of day, the data from the

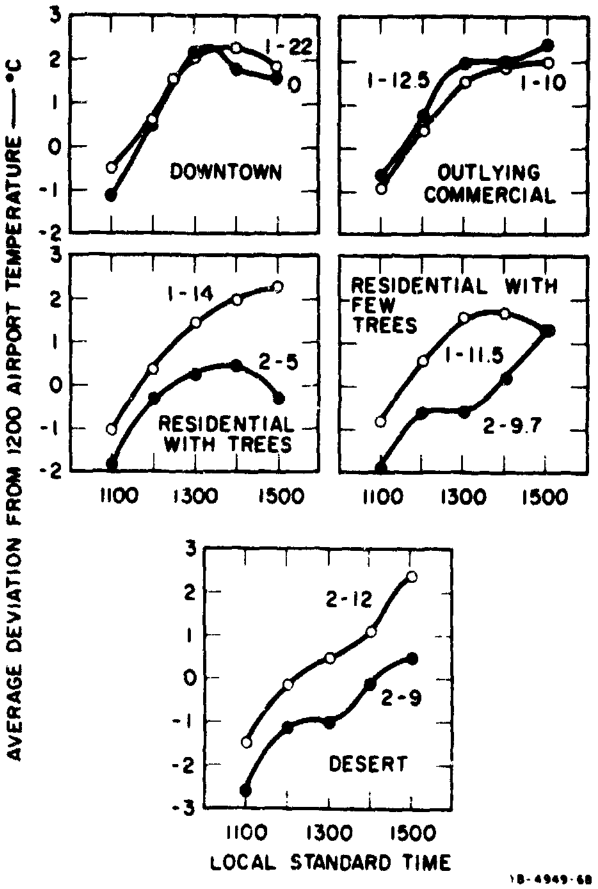



FIG. 17 CHANGES WITH TIME OF DAY OF AVERAGE RELATIVE DRY BULB TEMPERATURE FOR SEVERAL TYPES OF NEIGHBORHOODS IN ALBUQUERQUE

two appear to be comparable. This is also substantiated by the climatologies of the two areas. The difference between average July maximum temperature and average minimum temperature is 15°C for San Jose (U.S. Weather Bureau 1964a), and Albuquerque (U.S. Weather Bureau, 1965).

The range of average temperatures at each of the types of location shown in Fig. 17 is about the same over the hours for which averages could be calculated.

Four of the curves shown appear to reach definite maxima in the early afternoon. Two of these curves are for locations in the downtown area. One of the others is in a residential area with trees, just north of the airport (Route 2, Turn 5--see Fig. 8). This area experienced a thunderstorm at about 1500 on one of the sampling days, and the storm dropped temperatures in the area several degrees below other parts of Albuquerque. This one storm could be responsible for several tenths of a degree lowering of the 1500 average shown in Fig. 17. It seems likely that the temperature does not reach a maximum in the early afternoon of nonstorm days at this location.

The appearance of a maximum temperature in the downtown area earlier than in other parts of town agrees with what was observed for San Jose. Although the time of the downtown Albuquerque temperature maximum is earlier than for other parts of town, it is later than the time of maximum temperatures in the similar section of San Jose. This is true in general for all parts of Albuquerque. The maximum temperature occurs later in the day at a given area in Albuquerque than it does for a corresponding area of San Jose.

Weather in Albuquerque was less uniform than it was in San Jose, but it was by no means random. Generally it was clearer in the morning than in the afternoon. Cumulus clouds increased during the day and cumulonimbus clouds often developed in the late morning and in the afternoon. Sometimes these thunderclouds passed over various parts of Albuquerque. Often the rain falling from the clouds did not reach the ground but evaporated on its way down. Sometimes, however, large clouds produced heavy brief rain and caused large drops in temperature over limited areas. In general, the variations in weather from day to day did not produce severe disturbances in the overall typical temperature patterns which have been discussed.

D. New Orleans

The maps in Fig. 18 show the average deviation of wet and dry bulb temperatures observed in New Orleans from those measured at Moisant International Airport at noon. This airport is about ten miles west of the edge of the analyzed area shown in the figure. Table IV gives average temperatures and deviations from noon values for Moisant airport during the days of operation (see Table I).

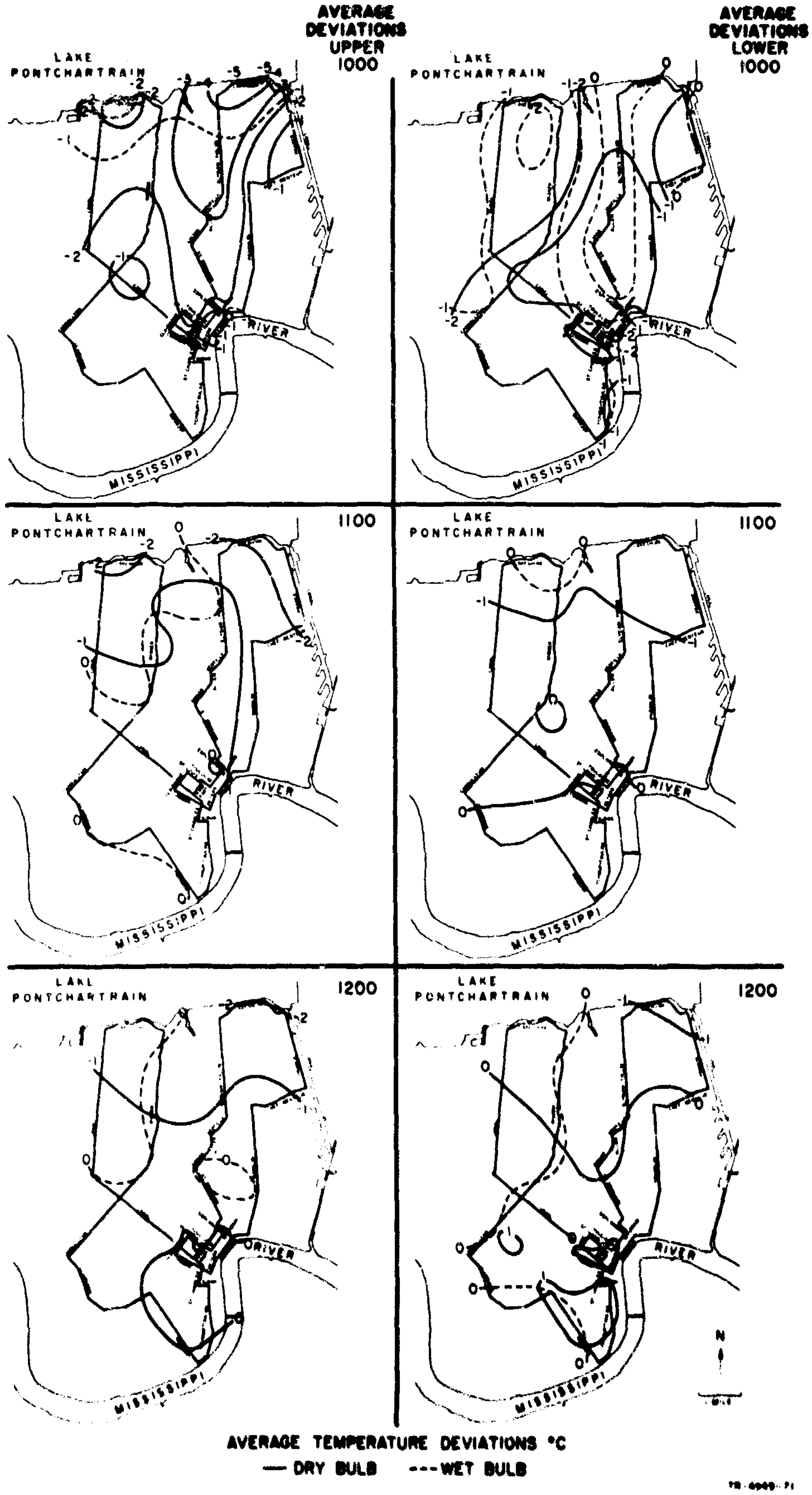
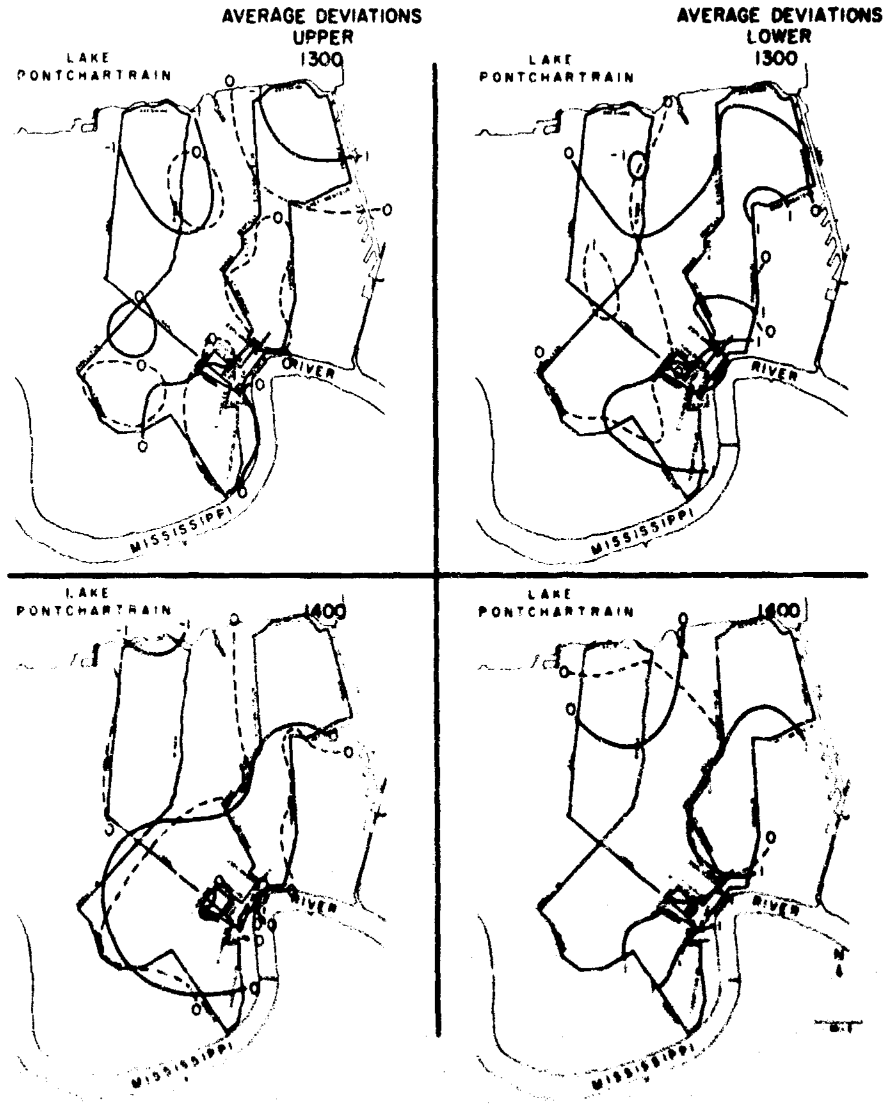



FIG. 18 AVERAGE RELATIVE WET AND DRY BULB TEMPERATURE FIELDS FOR NEW ORLEANS




AVERAGE TEMPERATURE DEVIATIONS °C

— DRY BULB  ---WET BULB

FIG. 18 Concluded

Table IV

HOURLY AVERAGES OF MOISANT INTERNATIONAL AIRPORT TEMPERATURES AND AVERAGE DEVIATIONS FROM NOON VALUES FOR DAYS OF OPERATION

| | Local Standard Time | | | | |
|---|---|---|---|---|---|
| | 1000 | 1100 | 1200 | 1300 | 1400 |
| Average Temperature (°C) | 29.9 | 30.4 | 30.9 | 31.2 | 31.6 |
| Average Deviation from 1200 (°C) | -1.0 | -0.5 | 0.0 | +0.3 | +0.7 |

A comparison of the maps for the upper and lower levels shows that the differences in the average dry bulb temperatures for the two levels is less in general for New Orleans than for the other two cities. In New Orleans, the difference between the 0.3-meter and the 2-meter temperatures generally average around 1°C, with the lower level the warmer, as in the other cities. As already noted, the difference between upper and lower average temperatures in San Jose and Albuquerque was usually between 1 and 2°C.

An exception to the usually lower lapse rates observed for New Orleans can be seen in the maps for 1000. At that time, differences between the two levels of greater than 3°C are found near Lake Pontchartrain at the northeast corner of the area. These differences between the two levels arise because of the tongue of cooler air penetrating in from the Lake at two meters, but largely unobserved at the lower level. It has not yet been determined if this phenomenon is or is not an artifact of the measuring and data analysis procedures.

As was true with the other two cities, the average dry bulb temperature fields are quite flat. The only major exception to this statement is the gradient associated with the tongue of cool air mentioned in the preceding paragraph. In this area the gradient reaches about 4°C/mile, approximately the same as the maximum values observed in the other cities. However, this relatively large gradient exists over a much larger area than was found in the other two locations.

The gradients in the average wet bulb temperature field are even smaller than in the dry bulb field. The strong gradients of the 2-meter, 1000 dry bulb field are not reflected in the wet bulb field at that level. However, the 0.3-meter wet bulb field does show some appreciable gradients, up to about 2°C/mile, in the center of the analyzed area.

The fields of wet bulb temperature are so flat that only one isotherm value appears on some maps, and for this reason it is not always possible to tell where the higher temperatures are found. In general, the average wet bulb temperatures are higher along the western side of the map. An exception to this is the 2-meter 1400 field, where the highest values are found in the northeastern corner.

The gross cooling effect of Lake Ponchartrain is easily seen in the dry bulb temperature fields. The coolest temperatures occur along the shore of the Lake and temperatures tend to increase away from the Lake, to the south. Considering the 2-meter values, the general effect of the Lake is modulated in different ways at different times. At 1000 there is the cool tongue of air extending in from the northeastern corner of the area. There is a smaller extension of cooler air at the northwestern corner and a ridge of warmer air extended northward between these two. By 1100 the two cool air pockets have weakened somewhat, and the warmer air extension from the south has become more pronounced.

The temperature field south of the lake shows only a slight undulation at 1200. The features of the preceding hour have smoothed out substantially. The warm air intrusion may have weakened and shifted eastward somewhat, although such continuity is not thoroughly established. In any event, by 1200 the average shows a cooler north-south band in the vicinity of the city park and other open areas (see Fig. 11) and a warmer strip along the residential area to the east. At 1300 this feature has become more pronounced. The amplitude of the temperature variation has increased from several tenths of a degree at 1200 to about one and a half degrees at 1300. The orientation of the features remains about the same--with the cooler air over the park and open areas, and the warmer over the nearby residential neighborhoods. Finally, this feature can still be seen at 1400. The orientation remains about the same, but the amplitude may have decreased slightly.

A study of the 2-meter dry bulb temperature fields in the downtown and French Quarter areas reveals some very interesting features. This part of town is roughly V-shaped with the downtown section centered on Common and the French Quarter centered on Bourbon (See Fig. 10). In general, the 2-meter dry bulb isotherms tend to outline the French Quarter and the northwestern boundary of the downtown area. The average temperatures in these areas are about 1/2°C warmer than most of the other nearby areas. The aforementioned outlining of the area is immediately apparent on all 2-meter maps shown except the 1100 map. If the -0.5°C isotherm were drawn on the 1100 map, it would be found to lie along the general boundaries of the area also. The warm air extends to the southwest of the downtown area in the afternoon. Much of this area is occupied by warehousing, factories, and rail yards.

As was true in the other cities, the 0.3-meter average dry bulb temperature fields show much the same features as do the 2-meter fields. The one major exception, the differences at 1000 in the northeastern part of the city, has already been discussed.

Most of the average wet bulb temperature fields shown in Fig. 18 are so flat that the dry bulb temperature field more or less defines the humidity field. If we assume the wet bulb temperature to be the same throughout the area, the dry bulb temperature fields imply the driest conditions downtown and in the French Quarter. Humidities are highest along the Lake. This simply confirms what one would expect.

The feature found in the average fields that was most frequently found in the individual 2-meter dry bulb temperature fields was the warm area located downtown and in the French Quarter. The other prominent features of the average temperature fields were also often observed, but not with as great consistency as were found for prominent average features in San Jose or Albuquerque. Temperature gradients in the individual maps were often much greater than those found in the averages. However, the larger gradients were usually associated with thundershowers. Even though the individual cases vary rather widely, it can be said that the average patterns are reasonably typical.

Four sets of observations were collected in New Orleans during the evening and early morning hours. On one of these nights it was overcast with some rain, but the others ranged from clear to scattered cloudiness and the winds were generally light. The results of these nighttime observations generally show a warm downtown area. This warm area is more pronounced during the night than during the day. During the later hours the effect of the Lake does not seem to be so strong. The north-south bands seen on the afternoon maps are apparent on several of the evening maps also.

The change of average 2-meter dry bulb temperature deviation with time is shown for several types of areas in Fig. 1?. One of the most evident features of these curves, when compared to those from San Jose and Albuquerque, is their smaller range of temperature. The climatology of the area shows this also. The difference between the July average maximum and minimum temperature is about 9°C for New Orleans (U.S. Weather Bureau 1964b) versus 15°C for San Jose and Albuquerque. This smaller range reflects the strong maritime influence on the climate of New Orleans. Also, the later occurrence of the temperature maximum in the downtown area is unlike that found in the other two cities. The maximum temperature occurs even later in the lakeshore and outlying commercial areas. The other curves shown in the figure suffer from a strong lack of agreement between the members of a pair supposed to illustrate the same type of temperature variation. These disagreements may arise because of thunderstorms, as in Albuquerque, or perhaps differences in solar heating due to street direction in places where the streets are quite narrow, such as in the French Quarter.

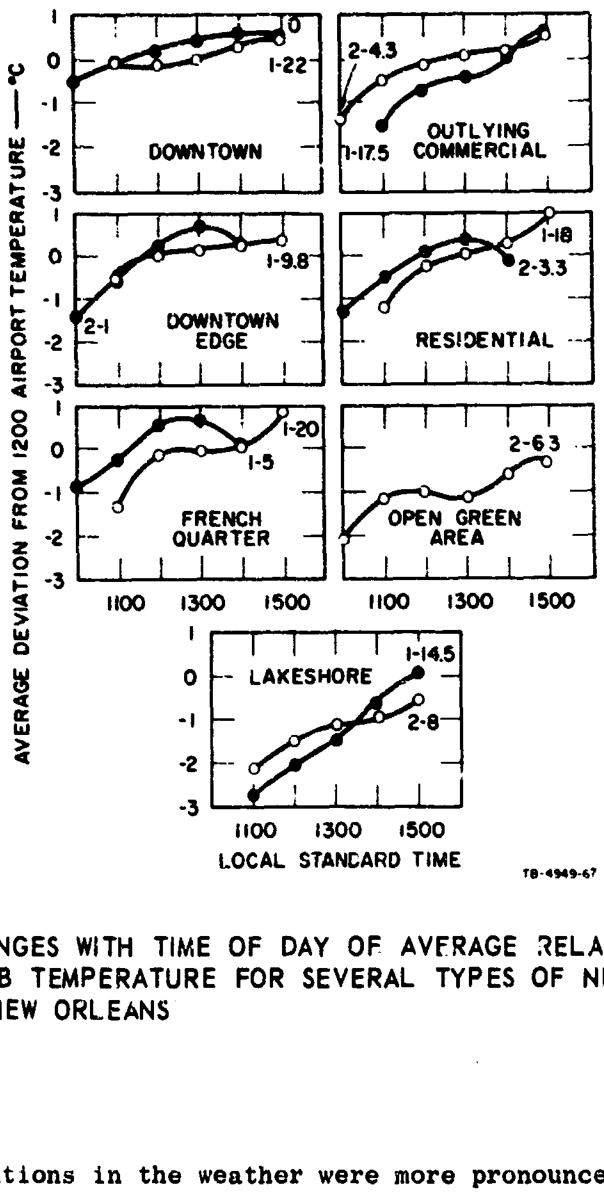



FIG. 19 CHANGES WITH TIME OF DAY OF AVERAGE RELATIVE DRY BULB TEMPERATURE FOR SEVERAL TYPES OF NEIGHBORHOODS IN NEW ORLEANS

Daily variations in the weather were more pronounced in New Orleans than in Albuquerque or San Jose and the frequency of occurrence of thundershowers was much greater. During the days of operation cloud cover was generally broken to overcast. Rain showers were frequent. Most commonly, afternoon winds were about 5 mph from the southeast and southwest, although other wind directions were also observed. Morning winds were about the same speed as the afternoon winds but less consistent in direction, most commonly, the morning winds were between southwest and north.

## VI FUTURE PLANS

It is evident that the data which have already been collected on this program will be of great help in answering many questions about the nature of temperature variations in the city, especially during summer daytime conditions. Thus far, the answers have been largely qualitative, so one of the prime objectives of future work must be the development of more quantitative statements and models of urban temperature anomalies. The other important objective of the program should be to integrate the data collected on the program with the data which have already been collected under nighttime conditions in other cities by other investigators.

In addition to the overall goals mentioned in the preceding paragraph there are a number of smaller problems to be pursued. These concern the effects of instrument exposure, of street orientation, of height above the street, and of city size and improvements in computational procedures.

The research approaches to be pursued during the coming year fall into three major categories:

1. Extending and modifying existing studies, empirical and theoretical, to develop a quantitative description of temperature effects in cities.
2. Using the field studies of others to extend our knowledge of temperature and humidity variations to conditions other than those covered by this program.
3. Extending the field program to collect data under a wider variety of conditions.

Several studies have been found in the literature that could serve as starting points for the type of research outlined in item 1 above. Other studies of this type will be sought. Those already uncovered fall into two categories: (1) empirical statements of the relationship between city and country temperatures for specific cities, and (2) theoretical statements concerning the relationship among temperature changes at the surface of the earth, the thermal properties of the earth, the radiative properties of the surface, and insolation. In the first category are Sundborg's (1951) investigations for Uppsala, and Chandler's (1965) for London. In the second category are the papers by Lettau (1951) and Lönnqvist (1962 and 1963). The empirical studies give information concerning the relative importance of several meteorological parameters (e.g., wind speed, cloud cover, etc.) to city-country temperature differences. They also indicate the relative strength of the temperature differences observed during the day versus nighttime differences and also the relative variations of strengths of these effects with season. The theoretical studies of daily surface temperature fluctuations are important because they relate these fluctuations to factors such as albedo, and the heat capacity and conductivity of the soil. The heat capacity and albedo of buildings and ground cover should be related to the temperature changes of their immediate surroundings. Studies of the type cited should serve as reasonable foundations for an investigation of temperature changes in urban areas.

The second research category encompasses our plans to use data collected by others to study conditions either not covered, or only lightly covered by this program. This includes nighttime conditions. Kratzer (1956) has compiled data from a large number of sources to illustrate aspects of temperature variations within a city. Many of the papers cited by Kratzer have been assembled during this program and some more recent studies have been added to the collection. These papers, and Kratzer's interpretation, will be of great help in estimating the magnitude of nighttime effects.

In addition to nighttime temperature variations, the changes of temperature with height above the surface will also be investigated. This is important to understanding conditions that might be encountered on the upper floors of buildings. Among available papers on this topic are those of Duckworth and Sandberg (1954) who have used Kytoon-borne thermistors to measure the lapse rates above cities at night, and DeMarais (1961) who compiled the data from a year's measurements over downtown Louisville, Kentucky. Studies of this type will be used in an effort to define the nature of the urban effects on the vertical temperature distribution and to incorporate these with the studies of horizontal changes.

As the San Jose airport measurements have shown, differences in observed temperature arising from differences in instrument exposure can be as large as temperature variations introduced by urban and geographical influences. For this reason the coming year's plans include a search of the literature for papers dealing with the effects of instrument exposure on observed temperatures. This would be followed by subsequent study to determine if there is any way in which instrument exposure differences can be evaluated and incorporated into climatological planning.

The final part of our planned program for the coming year is in the category of additional field work. This year's research has revealed areas where additional data would be welcome. First, it would be desirable to have data from an area where geographical effects do not tend to obscure urban effects. Such an area should be relatively flat and away from large bodies of water. An additional virtue would be the presence of several size cities and towns close to one another. Comparisons of the magnitude of urban effects as a function of city size could then be studied with a minimum of complications from climatic differences. No definite selection of a site has yet been made, but one area that has been considered is the Dallas-Fort Worth area in Texas. Early in the coming year sites will be studied and one selected. A preliminary visit will be made to set out routes and to search for instrument locations and data sources.

It would be desirable if our field work covered greater periods of the day than was done for most of the tests conducted during the past year. This will probably be done by using only one vehicle at a time. The interval between measurements would be longer, but two drivers could continue operations for as much as 16 hours per day regularly and for 24-hour periods on some occasions. This type of measurement would help to connect day and night effects for one location, which, in turn, would be helpful in the interpretation of the nighttime results of other investigators. The field program is not planned to be as extensive as during the past year. It will probably be limited to about a month in an area outside the San Francisco Bay area plus a few more tests in San Jose.

It is planned to add an additional stationary instrument, a pyrheliometer, to the hygrothermographs used this year. Interpretation of diurnal temperature changes in terms of the thermal properties of the different areas would probably be helped considerably by the availability of records of insolation. Pyrheliometer data have been obtained from San Jose and Albuquerque, but there are gaps in the record. By using a project instrument, it is hoped that other possible sources of sunshine data can be supplemented to ensure a continuous record.

Of course, there will be a continued effort to improve data analysis methods, including interpolation procedures and better methods of handling humidity parameters. Such improvements may also include the addition of data from more points in each city. These data are available on the chart records and could be added to the compilation. It might help to answer some questions concerning the effects of street orientation or other relatively small-scale phenomena.

In summary, it is planned to use the data already collected in conjunction with some additional field data, data to be collected this summer, and the studies of other investigators to compile a comprehensive description of city-induced temperature effects. Investigations of vertical temperature variations, of instrument exposure effects, of nighttime variations, and of the effects of city size will be sought and incorporated into the work. Our data will be studied using existing theory, and if possible, interpreted in terms of theoretical or empirical models. Some field studies will be conducted to help integrate our data with the results obtained by other investigators.

ACKNOWLEDGMENTS

As is true of programs of this size, there is a long list of people and institutions that contributed to the performance of the work.

The list starts with Mr. C. Donald Ahrens, who is responsible for the collection of half the data and for many constructive comments and suggestions during the course of the field work. Mrs. Olive Chichester did most of the keypunching and the plotting of results on maps for analysis. Mr. Vincent Lauricello developed the computer programs used to process the data and helped with the preparation of the part of the manuscript dealing with that phase of the program. Messrs. Tom Enkoji and Albert F. Smith contributed greatly to the design and construction of the temperature measuring systems. Mr. F. S. Duckworth and Mr. J. S. Sandberg gave us much very good advice concerning the design of equipment and the planning of the field program.

Others who helped by providing space for instruments and access to data are the Office of Civil Defense in San Jose, San Jose State College, San Jose Municipal Airport, the University of New Mexico, the University of Albuquerque, New Orleans Public Services Co., U.S. Department of Agriculture Southern Regional Research Station, and the U.S. Weather Bureau offices in Albuquerque and New Orleans.

In addition, we wish to thank the police departments of San Jose, Albuquerque, and New Orleans for their cooperation.

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Appendix A

# DETAILED ROUTE DESCRIPTIONS

## Appendix A
## DETAILED ROUTE DESCRIPTIONS

Maps of the temperature measurement routes for each of the cities are given in the main text of this report. These maps show topography, built-up areas, and photographs of some typical neighborhoods. This Appendix describes in detail the nature of the areas through which the routes pass. The descriptions are given for each leg of the route from beginning to end.

San Jose Route 1 (Figs. 6 and 7)

Start (Market and Santa Clara) to Turn 1 (Alum Rock and Capitol) goes through the multistory downtown area for the first 1/4 mile. The remainder of the route has commercial establishments lining the street and residential areas behind. There are increasing amounts of open space for the last mile or so.

Turn 1 to Turn 2 (Capitol and Hostetter) goes through about 1/2 mile of residential area mixed with large open plots. The rest of the route passes orchards and large open plots.

Turn 2 to Turn 3 (Hostetter and Lundy) passes through orchards.

Turn 3 to Turn 4 (Lundy and Murphy) passes through orchards.

Turn 4 to Turn 5 (Murphy and Oakland) passes through orchards.

Turn 5 to Turn 6 (Oakland and Hedding). About 2/3 of this part of the route passes through an area that is primarily a mixture of orchards and farmlands. The last 1/3 of the distance goes through a mixed area of residential and commercial buildings.

Turn 6 to Turn 7 (Hedding and 1st) goes through a residential area. For the first half of the distance the residential buildings are mixed with warehouses.

Turn 7 to Turn 8 (1st and De La Cruz). About half of this part of the route passes through an area of mixed character, including commercial buildings, residential apartments, and some open areas. The second half of the distance goes through an area of open fields.

Turn 8 to Turn 9 (De La Cruz and Kifer) goes through an area of primarily open fields.

Turn 9 to Turn 10 (Kifer and LaFayette) passes from a region of open fields into an industrial and warehousing area.

Turn 10 to Turn 11 (LaFayette and Harrison) passes about one mile of industry and warehousing, and then passes about 1/2 mile of commercial area.

Turn 11 to Turn 12 (Harrison and Alviso) to Turn 13 (Alviso and De La Cruz) goes through several blocks of older residential area.

Turn 13 to Turn 14 (De La Cruz and Coleman) crosses an overpass above rail yards.

Turn 14 to end (Market and Santa Clara). The first half mile is through an industrial area with large open areas, followed by about 1/2 mile with the airport on the northeast side of the road and more industrial area on the southwest. This is followed by about 1/2 mile of rail yards to the southwest of the route and commercial areas to the northeast. The remainder of this leg goes through a commercial area, with about the last 1/2 mile being in the multistory, downtown area.

San Jose Route 2 (Figs. 6 and 7)

Start (Santa Clara and Market) to Turn 1 (1st and Keyes) goes through the multistory downtown area for about 1/3 mile and the remainder goes through a commercial area.

Turn 1 to Turn 2 (Story and King) goes through a mixed commercial and warehousing area for about 3/4 mile. The route then passes about 1-1/4 miles of open area, park, and orchards with some commercial buildings along the road. The remainder of the leg has open areas northwest of the road and a mixture of residential and commercial buildings to the southeast.

Turn 2 to Turn 3 (King and Tully) goes through a residential tract with few trees. Increasing amounts of open space appear for the last 3/4 mile before Turn 3.

Turn 3 to Turn 5 (Tully, Curtner, and Monterey). Between June and September, Turn 4 was eliminated because of a realignment of Tully so that it continued on as Curtner after crossing Monterey. This leg passes through open areas, orchards, and the Santa Clara County Fairgrounds.

Turn 5 to Turn 6 (Curtner and Lincoln) goes through about 1/3 mile mixed industrial area and open space. The route then passes by about 3/4 mile of open and orchard areas, with the remainder of the way to Turn 6 going through a residential area with some large trees.

Turn 6 to Turn 7 (Lincoln and Willow) goes through a residential area except for first and last quarter mile. The first quarter mile is an area of mixed residential and commercial buildings and the last quarter mile goes through a neighborhood shopping area.

Turn 7 to Turn 8 (Willow and Meridan) goes through a residential area with some large trees.

Turn 8 to Turn 9 (Meridan and Hamilton) passes through a residential area, but there are some commercial buildings along the road.

Turn 9 to Turn 10 (Hamilton and Bascom). Half the way to Turn 10 goes through a residential area with some light commercial activity along the road. The second half of this distance passes through open areas and orchards.

Turn 10 to Turn 11 (Bascom and Moorpark) goes through large open areas and orchards intermixed with commercial area.

Turn 11 to Turn 12 (Moorpark and Meridan) goes past San Jose City College, south of the route, for about 1/4 mile. The rest of the way passes open, orchard, and residential areas.

Turn 12 to Turn 13 (Meridan and San Carlos) passes a commercial area.

Turn 13 to Turn 14 (San Carlos and 4th) goes through commercial areas with the last 1/2 mile or so marking the approximate southeast edge of the main downtown central area.

Turn 14 to Turn 15 (4th and Julian) goes past San Jose State College to the northeast of the route. The central downtown area has this part of the route as an approximate northeast boundary.

Turn 15 to Turn 16 (Julian and Plèasant). The first 1/3 of this leg passes through a mixture of multifamily dwellings and commercial buildings. The second 1/3 goes along the northwest edge of the central downtown area, and the last 1/3 goes through a warehousing area.

Turn 16 to Turn 17 (Pleasant and Santa Clara) passes an older residential area.

Turn 17 to Turn 18 (Santa Clara and Vine) passes a block of commercial buildings.

Turn 18 to Turn 19 (Vine and Park) goes by some open areas, parking lots, and demolished buildings.

Turn 19 to Turn 20 (Park and 2nd) goes by open areas, parking lots for about half the distance to Turn 20, then through the multistory downtown area for the rest of the way.

Turn 20 to Turn 21 (2nd and St. John) goes through a multistory central downtown area.

Turn 21 to Turn 22 (St. John and Market) goes past one block of park area northwest of route. The remainder passes through the downtown commercial area.

Turn 22 to end (Market and Santa Clara) goes through a multistory downtown commercial area.

Albuquerque Route 1 (Figs. 8 and 9)

Start (Coal and 2nd) to Turn 1 (2nd and Mountain) passes along the edge of the downtown commercial area.

Turn 1 to Turn 2 (Mountain and 5th) passes along the edge of the downtown commercial area.

Turn 2 to Turn 3 (5th and Coal) passes through some residential area with mature trees, and then through the central downtown area.

Turn 3 to Turn 4 (Coal and 3rd) passes along the edge of the downtown commercial area.

Turn 4 to Turn 5 (3rd and Bridge) goes through an older residential area.

Turn 5 to Turn 6 (Bridge and Coors) goes through a mixed area of light commercial and residential buildings. Route crosses the Rio Grande shortly after Turn 5. Some large open plots are found along the route for the last mile or so before Turn 6.

Turn 6 to Turn 7 (Coors and Central) passes large open plots with commercial buildings along the road and residential areas behind the road.

Turn 7 to Turn 8 (Palisades and Atrisco) goes by residential areas and open plots.

Turn 8 to Turn 9 (Atrisco and Central) passes along the palisades of the Rio Grande and open plots with some residential areas.

Turn 9 to Turn 10 (Central and Rio Grande) crosses the Rio Grande and then passes through a commercial area.

Turn 10 to Turn 11 (Rio Grande and Candelaria) goes through a commercial and residential mixture along the road, with intermixed residential and large open plots just off the road.

Turn 11 to Turn 12 (Candelaria and 4th) goes through a largely residential area with some commercial buildings and some large open plots.

Turn 12 to Turn 13 (4th and Mountain) goes through a commercial area.

Turn 13 to Turn 14 (Mountain and 8th) goes through a residential area.

Turn 14 to Turn 15 (8th and Lomas) goes through a residential area.

Turn 15 to Turn 16 (Lomas and Luna) goes through a predominantly residential area with some commercial buildings.

Turn 16 to Turn 17 (10th and Coal) goes through a predominantly residential area with some commercial buildings.

Turn 17 to Turn 18 (Coal and 7th) goes through a predominantly residential area with some commercial buildings.

Turn 18 to Turn 19 (7th and Tijeras) goes along the edge of the downtown commercial area.

Turn 19 to Turn 20 (Tijeras and Broadway) goes through a commercial area.

Turn 20 to Turn 21 (Broadway and Marquette) goes through a commercial area.

Turn 21 to Turn 22 (Marquette and 3rd) passes a commercial area.

Turn 22 to Turn 23 (3rd and Coal) goes through the downtown commercial center.

Turn 24 to end (Coal and 2nd) passes along the edge of the downtown commercial area.

Albuquerque Route 2 (Figs. 8 and 9)

Start (2nd and Coal) to Turn 1 (Coal and Broadway) crosses a bridge over the rail yards.

Turn 1 to Turn 2 (Broadway and Miles) goes by a mixture of residential and commercial buildings.

Turn 2 to Turn 3 (Gibson and Yale) passes by large open areas and some commercial buildings along the road.

Turn 3 to Turn 4 (Yale at Airport entrance) goes through large open areas.

Turn 4 to Turn 5 (Girard and Highland) goes past the airport, through large open areas, and into a residential area with large trees about 3/4 mile before Turn 5.

Turn 5 to Turn 6 (Zuni and Wyoming) goes by a residential area for about the first one mile, then through a mixture of commercial and residential buildings with some large open plots.

Turn 6 to Turn 7 (Wyoming and Central) goes through a commercial area.

Turn 7 to Turn 8 (Central and Juan Tabo) goes past commercial buildings along the highway and large open plots off the highway, for about half way. It then passes mostly open areas (except for some commercial building along the highway edge.

Turn 8 to Turn 9 (Juan Tabo and Candelaria) passes the open spaces at the edge of town, with one or two small commercial shopping areas along the way.

Turn 9 to Turn 10 (Candelaria and San Pedro) goes past open spaces for one mile, then through a newer residential area with a few large trees and some large open plots.

Turn 10 to Turn 11 (San Pedro and Montgomery) goes through a residential area with some large trees, and then passes by an open area for the last several blocks before Turn 11.

Turn 11 to Turn 12 (Montgomery and Carlisle) goes through open areas along the edge of town.

Turn 12 to Turn 13 (Carlisle and Lomas) goes through about 3/4 mile of open areas, about 1-1/2 miles of mixed light commercial and residential areas, and then through a residential area to Turn 13.

Turn 13 to Turn 14 (Lomas and University). The first half goes through a residential area and the second half through a university campus and hospital area.

Turn 14 to Turn 15 (University and Grand) passes through an area of university residences and campus.

Turn 15 to Turn 16 (Grand and Edith) goes through a residential area with mature trees.

Turn 16 to Turn 17 (Edith and Lomas) goes through a residential area.

Turn 17 to Turn 18 (Lomas and 4th) goes through a commercial area.

Turn 18 to Turn 19 (4th and Coal) passes through the center of the downtown commercial areas.

Turn 19 to end (Coal and 2nd) goes along the edge of the downtown commercial area.

New Orleans Route 1 (Figs. 10 and 11)

Start (St. Charles and Common) to Turn 1 (Tulane and Claiborne) passes through an area of multistory downtown office buildings.

Turn 1 to Turn 2 (Claiborne and St. Louis) passes along the edge of the downtown area and through an area of multistory buildings and apartments.

Turn 2 to Turn 3 (St. Louis and Basin) goes through an area of warehousing and apartments.

Turn 3 to Turn 4 (Basin and Toulouse) goes past more warehousing and apartments.

Turn 4 to Turn 5 (Toulouse and Bourbon) passes through the French Quarter, with narrow streets, two to three story houses, and apartments built with no space between buildings.

Turn 5 to Turn 6 (Bourbon and Esplanade) goes through more of the French Quarter.

Turn 6 to Turn 7 (Esplanade and Rampart) is a divided street with trees on the median, along the edge of the French Quarter.

Turn 7 to Turn 8 (Rampart and St. Bernard) is a divided street through a mixed area of apartments and commercial buildings.

Turn 8 to Turn 9 (St. Bernard and Broad) goes past about 1/2 mile of mixed commercial and residential buildings. It then passes an area which is primarily residential but which has some commercial activity. There are some trees in the area.

Turn 9 to Turn 10 (Allen and Gentilly) goes through a largely residential area.

Turn 10 to Turn 11 (Gentilly and Fairmont) passes the large grassy areas of Dillard University to the north and a residential area to the south for half of the way. The rest of the way goes through a commercial area.

Turn 11 to Turn 12 (Fairmont and Monterey) to Turn 13 (Monterey and Elysian Fields). Three right-hand turns through a residential neighborhood are used instead of a left turn directly on Elysian Fields.

Turn 13 to Turn 14 (Elysian Fields and Lakeshore) goes along a divided street with grass, shrubbery, and trees on the median. The area is mostly residential until about 1/2 mile from Turn 14; then there are large open grassy areas to the turn.

Turn 14 to Turn 15 (Lakeshore and Simon) goes through large open grassy park areas along the shore of Lake Ponchartrain.

Turn 15 to Turn 16 (Simon and France) is one block of open area.

Turn 16 to Turn 17 (France and Chef Menteur) passes industrial and harbor areas to the east, and residential areas to the west.

Turn 17 to Turn 18, 19 (Gentilly and Franklin). Turn 18 is a right turn onto Franklin, Turn 19 is a U-turn 1/2 block from Turn 18. From Turn 17 the area is commercial for about 3/4 mile. The route then passes an area of large residences and trees.

Turn 19 to Turn 20 (Franklin and Decatur) goes past a residential area with many large trees for about 3/4 mile, commercial buildings for about 3/4 mile, and then residential area with few trees for about one mile. It is a divided street to this point. The last 1/2 mile is undivided street through an area of residences similar to those in French Quarter, but less compactly arrayed.

Turn 20 to Turn 21 (Decatur and Peters) goes through an area of warehousing and some residences for about 1/2 mile, then through an area of French Quarter buildings, the French Market, and industrial buildings.

Turn 21 to Turn 22 (Tchoupitoulas and Common) goes through a riverfront area of mixed commercial, industrial, and warehousing activity.

Turn 22 to end (Common and St. Charles) goes through an area of multistory downtown buildings.

New Orleans Route 2 (Figs. 10 and 11)

Start (Common and St. Charles) to Turn 1 (St. Charles and Girod) goes through an area of mostly multistory downtown commercial buildings.

Turn 1 to Turn 2 (Girod and Tchoupitoulas) is an area of three and four story brick, stone, and plaster buildings.

Turn 2 to Turn 3 (Tchoupitoulas and Jackson) is an extensive area of manufacturing and warehousing along the riverfront.

Turn 3 to Turn 4 (Jackson and Claiborne) goes through a residential area with a few trees for about the first 1/2 mile. There are many mature trees for the remainder of the way to Turn 4.

Turn 4 to Turn 5 (Claiborne and Carrollton) goes along a divided street with grass and shrubbery on the median. It is mostly commercial for about the first mile, then residential with mature trees to Turn 5.

Turn 5 to Turn 6 (Wisner and Esplanade) goes through an area that is mostly commercial along the street and residential behind. The last 1/2 mile is residential with large trees.

Turn 6 to Turn 7 (Beauregard and Lakeshore) passes between a large open park area on the west and Bayou St. John to the east, with large residences beyond the Bayou. The last 1/3 mile is residential to the west of route.

Turn 7 to Turn 8 (Lakeshore and Canal Blvd.). Lake Pontchartrain is north of the route and large open grassy areas are south of the route.

Turn 8 to Turn 9 (Canal Blvd. becomes Canal St.) goes through a mostly residential area with large lawns and some trees. The street is divided with grass and shrubbery on the median.

Turn 9 to Turn 10 (Canal St. and St. Charles) goes through a residential area, mostly two-story with large mature trees for about the first 1-3/4 miles. It then passes about 3/4 mile of commercial office buildings, with trees. The last 3/4 mile before Turn 10 is through the multistory downtown commercial area.

Turn 10 to end (St. Charles and Common) is one block of multistory down-
town commercial buildings.

Canal Street is an exceptionally wide main street, but other streets in the downtown area and in the French Quarter are generally narrow.

Appendix B

# ANNOTATED BIBLIOGRAPHY

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Appendix B

# ANNOTATED BIBLIOGRAPHY

Because this report has not dealt extensively with the general field of urban temperatures but is mainly concerned with the techniques and preliminary results of this one program, the list of references does not include many sources of information about urban temperatures and related topics. In order to provide the reader with a list of source materials, an annotated summary of items collected on this research program is presented in this appendix. This list is divided into two sections, the first is a list of bibliographical sources. The second section lists most of the papers, reports, and books which have been assembled during the course of this research.

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Sundborg, A., Climatological Studies in Uppsala, with Special Regard to the Temperature Conditions in the Urban Area, Geographica No. 22, Universitet Geografiska Institutionen, Uppsala, 1951, 111 p. As already noted, this work has an extended list of references. This paper is a substantial extension of the work reported in the preceding reference. It includes a review of urban climatological literature, a description of the area around Uppsala and the general climatology of the area, a description of the instrumentation and methods used in the temperature surveys, a presentation of the observed horizontal variations in the Uppsala region, the development of regression equations to relate daytime and nighttime differences between city and country temperatures to simple meteorological elements, and a discussion of the significance of the physical factors governing urban-rural temperature contrasts.

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13. ABSTRACT

The report describes portable automobile-mounted, recording, temperature measurement systems using ventilated radiation-shielded thermistor elements to measure wet and dry bulb temperatures at heights of 0.3 and 2 meters with an accuracy of about ±0.25°C. The units were used on two vehicles to survey horizontal temperature fields in San Jose, Calif.; Albuquerque, N.M.; and New Orleans, La., during the summer of 1966. About three weeks were spent in each city, covering areas from the city's center to its edge. Chart records of temperature were transferred to punched cards and processed. They were interpolated to common hours and averaged for about 50 selected locations in each city. The averages are in a relative form, where each of the 18 to 20 thousand individual temperatures had subtracted from it that day's noon airport temperature. Relative wet-bulb temperature fields are also presented. Daytime results are stressed. Preliminary analyses indicate that the effect of built-up areas, as distinct from other influences, is to raise the temperature by about 1/2°C during the day. Shaded or grassy spaces are about 1/2°C cooler than their unshaded surroundings. Future plans are discussed.

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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Temperature fields | | | | | | |
| Urban | | | | | | |
| Wet-bulb temperature fields | | | | | | |

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