Three Aspects of the Urban Climate of Detroit-Windsor[1]

MARIE SANDERSON, IMAIYAVALLI KUMANAN,[2] TERRY TANGUAY[3] AND WILLIAM SCHERTZER[4]

Dept. of Geography, University of Windsor, Windsor, Ontario, Canada

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ABSTRACT

In the present study, a beginning is made into the investigation of the effect of the urban area on the microclimate of Detroit-Windsor. Diurnal and seasonal urban-rural temperature differences were investigated using three-hourly temperature data for a 10-year period for City, Metropolitan and Windsor airports. Maximum differences were observed in early morning hours and minimum or zero differences at midday. Seasonally, maximum differences were observed in August–October and minimum differences in January–March. The differences between urban and rural atmospheric transmissivity ratios were investigated for clear winter days using a Kipp and Zonen pyranometer and a model to predict incoming solar radiation at the top of the atmosphere. Urban ratios averaged 9% less, and under calm conditions, reached 25% less than in adjacent rural areas. Data from the South Eastern Michigan Council of Governments precipitation network in the Detroit area were used in a comparison with regional seasonal precipitation patterns. Although the urban area or microscale precipitation pattern did not appear to differ on an annual basis from the regional precipitation pattern, on a seasonal basis Detroit received less precipitation than the surrounding rural areas in autumn and winter and about 20% more in summer.

1. Introduction

Over 70% of all North Americans now live in cities of more than 100,000 people and the forecast is that this percentage will continue to increase. What is the effect of these urban areas on the microclimate of the city, the climate in which the urban dwellers, men, plants and other living things, must live? How does the climate of the urban area differ from that of the surrounding rural areas? Are screen height temperatures increased or decreased and, if so, when and by how much? When and by how much is precipitation increased or decreased? What is the effect of the city's atmosphere on incoming solar radiation, and the radiation balance? All of these aspects of the microclimate will be influenced, of course, by the macro- and mesoclimate of the city being studied, and it is extremely difficult to separate meso- and microclimate effects. It is nevertheless important that the climate of each large metropolitan area is understood and that measurements of the important parameters are begun now, so that future effects of increasing city size or air pollution measures can be ascertained.

The present report is the result of recent research at the University of Windsor on three aspects of the urban climate of the Detroit-Windsor area: 1) the magnitude and variability of the urban heat island, 2) some winter transmissivity ratios, and 3) regional and microscale precipitation patterns. The report is preliminary for the latter two items, since research on radiation, incoming solar and net, and also on urban and rural precipitation is being continued. A report on the general climate of the Detroit-Windsor area was included in the International Joint Commission report on air pollution in the St. Clair-Detroit River area (1971). Munn *et al.* (1959, 1969) have written of the pollution climatology of the area, and Strommen (1968) has recently discussed the urban effects on precipitation in Detroit.

A map of the two cities is seen in Fig. 1, with built-up areas and central business district boundaries obtained from the City Planning Board (for Windsor) and the Doxiades' report (for Detroit). The urban area extends about 30 mi in an east-west and 20 mi in a north-south direction. Population for greater Detroit is more than 4,000,000, for Windsor 200,000. The area is very flat, the floor of former glacial Lake Maumee, at about 600 ft MSL. Some glacial moraines rise to about 900 ft to the northwest of Detroit. The mile wide Detroit River, which forms the international border, separates the two cities. However, both of these topographic features probably have less effect on the mesoclimate than Lake St. Clair to the northeast, and the western part of Lake Erie to the south. Both are shallow bodies of water, ice covered in winter, and with high surface temperatures in summer. Unfortunately, there has been no study of the lake breeze in the Detroit-Windsor area.

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[1] Research sponsored by the Atmospheric Environment Service, Toronto, Canada.

[2] Present affiliation: University of Ceylon, Colombo.

[3] Present affiliation: Canadian Armed Forces.

[4] Present affiliation: Graduate student, Geography, McMaster University, Hamilton, Ontario, Canda.

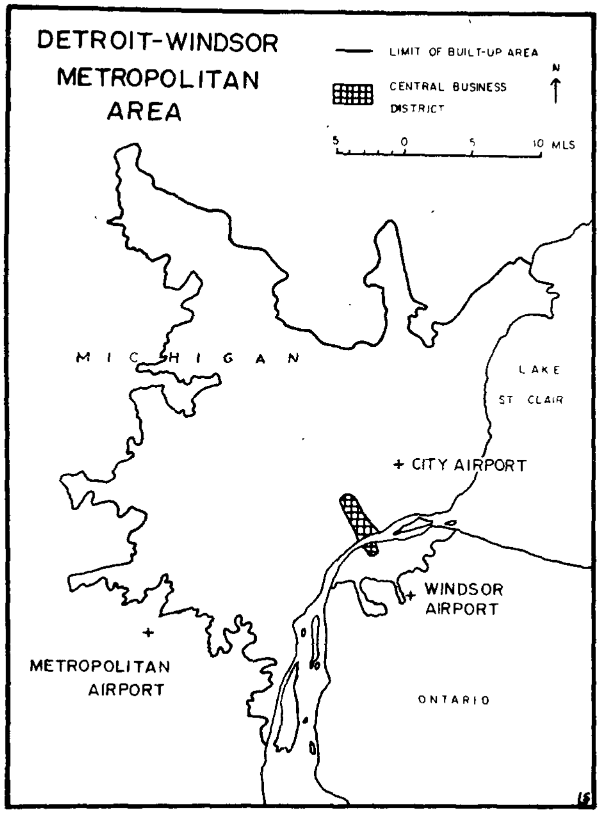

FIG. 1. Location of study area, Detroit-Windsor, showing limit of built-up area, central business district, and three airports.

2. The urban heat island

Probably the longest studied of any aspect of the urban climate is that of the urban heat island, since Howard in 1809 tabulated temperature differences between the city of London and its surrounding countryside (Chandler, 1965). Mean annual temperature excesses of urban over rural temperatures are listed by Landsberg (1970) as 1.3F for cities of over 1,000,000 population, 1.1F for cities of 500,000–1,000,000 and 1F for cities of 100,000–500,000. The existence of the urban heat island is usually explained as the effect of the city itself on the natural energy balance, and the artificial heat added by residential and industrial buildings. A satisfactory accounting of the complete energy balance of any city is still lacking, and according to Landsberg, must await the gathering of data above the city by remote sensors. The present study examines the magnitude and variability, diurnally and seasonally, of the heat island of Windsor-Detroit. A few explanations are suggested.

There are three airports in the area (see Fig. 1 for location): Metropolitan "Metro." (west of Detroit), City (well within the built-up area), and Windsor (southeast of the urban area). Air temperatures for these locations are published on a 3-hr basis, and this offers an opportunity to study urban-rural temperature differences throughout the day and seasonally. The times used are 0100, 0400, 0700, 1000, 1300, 1600, 1900 and 2200 hours, for a 10-year period, 1960–69. City airport was considered an "urban" location although recent research has shown that city airports have lower air temperatures than downtown areas, and the city airport figures probably underestimate the maximum urban temperatures. The two rural airports are outside the urban heat island since it has been reported that temperatures are lower outside the built-up area (Peterson, 1970). However, airport temperatures have usually been found to be higher than at nearby rural stations, so probably the "rural" temperatures in this study are overestimated. Thus, the urban-rural temperature differences in the present study probably underestimate the difference between downtown and rural temperatures.

A t-test was used in the study, to test for significant differences between urban and rural temperatures, of the form

$$t=\frac{\bar{d}}{s_{\bar{d}}},$$

where $\bar{d}$ is the mean temperature difference and $s_{\bar{d}}$ the standard error of difference. Since the sample size used here is very large, the value of t is the same as that from the normal distribution tables. (Hence, a one-tailed test, $t=2.33$ at the 1% level for large n, was used).

The following tests were made:

1) Data for all eight observation hours were combined and t statistics computed for each year, 1960–69.

2) The t statistic was computed for each sample hour for the 10-year period 1960–69.

3) The data for the eight sample hours were combined by months for the 10-year period to obtain monthly temperature differences.

4) The data for each sample hour were analyzed by months to obtain diurnal temperature differences for each month.

The frequency of significant temperature differences for each hour and daily are shown in Table 1. Significant differences at City-Windsor occur in the all day data 100% of the time, but percentages are lower for City-Metro. The nighttime hours show high percentages of significant differences but the daytime percentages are surprisingly low; at 1300 hours for City-Metro the highest percentage of significant difference is 40%.

The statistical tests also show the magnitude of the temperature differences, and Fig. 2 indicates the yearly variation of the mean differences.[5] The average mean difference was 1.5F for City-Metro and 2.0F for City-Windsor. These values are higher than the average annual temperature differences given by Landsberg,

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[5] The graphs in Figs. 2–5 were prepared using an IMB S/360 computer and Calcomp plotter.

TABLE 1. Frequency (percent) of significant temperature differences.

City—Metro

Period	0100	0400	0700	1000	Time 1300	1600	1900	2200	All day	Average
Year	100	100	100	70	30	20	100	100	100	100
Jan.	70	70	70	40	30	20	80	70	90	80
Feb.	60	50	50	10	10	10	40	60	60	40
Mar.	60	60	70	30	20	10	50	60	60	60
Apr.	70	70	80	20	20	20	50	80	80	60
May	90	100	80	40	30	20	50	90	100	70
June	80	90	90	60	30	10	50	80	90	90
July	90	90	90	50	20	10	50	100	90	90
Aug.	100	100	100	70	40	10	70	100	100	100
Sep.	100	100	100	60	30	30	90	100	100	100
Oct.	100	100	100	60	40	30	100	100	100	100
Nov.	80	80	80	60	30	30	80	80	80	80
Dec.	60	50	50	40	30	30	70	80	90	60

City—Windsor

Period	0100	0400	0700	1000	Time 1300	1600	1900	2200	All day	Average
Year	100	100	100	100	100	100	100	100	100	100
Jan.	90	90	70	60	60	90	100	100	100	100
Feb.	80	70	70	50	80	80	80	90	100	100
Mar.	100	90	90	80	100	100	100	90	100	100
Apr.	100	100	100	80	90	80	90	100	100	100
May	100	100	80	90	100	100	100	100	100	100
June	100	80	90	90	100	90	100	100	100	100
July	100	90	90	80	80	90	90	100	100	100
Aug.	100	90	90	90	100	90	100	100	100	100
Sep.	100	90	80	90	100	90	100	100	100	100
Oct.	90	80	90	90	90	90	100	100	100	100
Nov.	90	80	90	70	100	100	100	100	100	100
Dec.	100	80	80	70	80	80	90	100	100	100

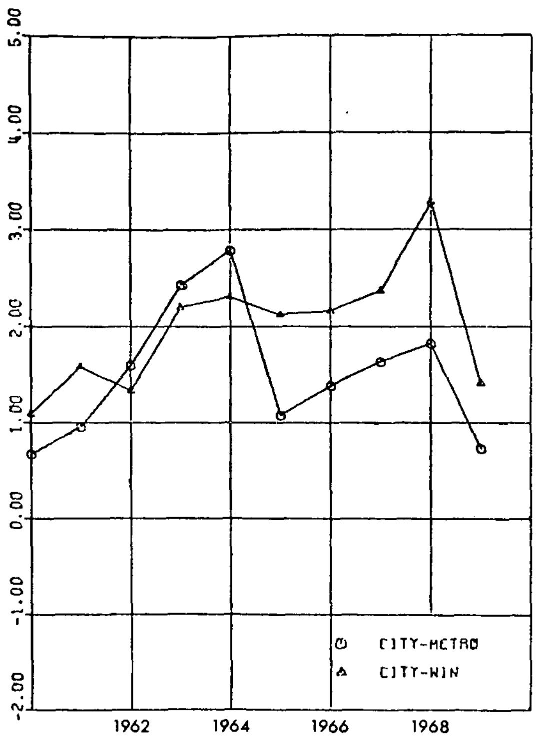

FIG. 2. Mean temperature differences (City-Metro and City-Windsor) by years. Each data point is the average of 365×8 (2920) temperature differences.

calculated from the daily maxima and minima, for cities of comparable size: Chicago, 1.1F; Washington, 1.1F; Philadelphia, 1.4F.

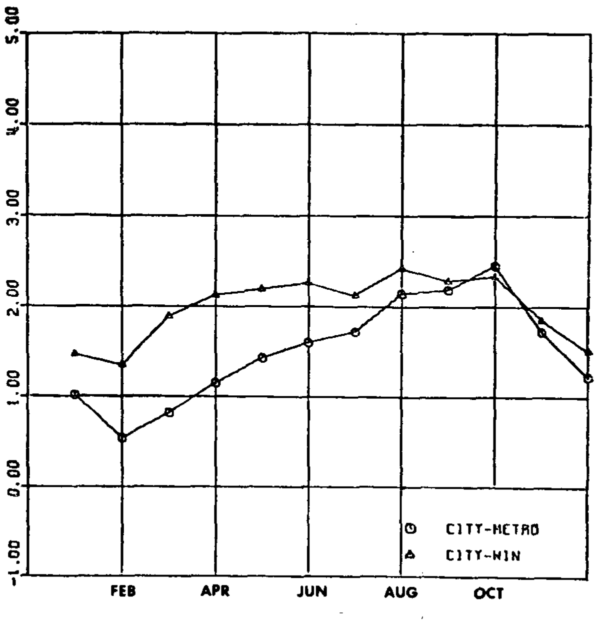

FIG. 3. Monthly variation of temperature differences (City-Metro and City-Windsor). Each data point is the average of the 8 readings for each day for 10 Januarys, 10 Februarys, etc.

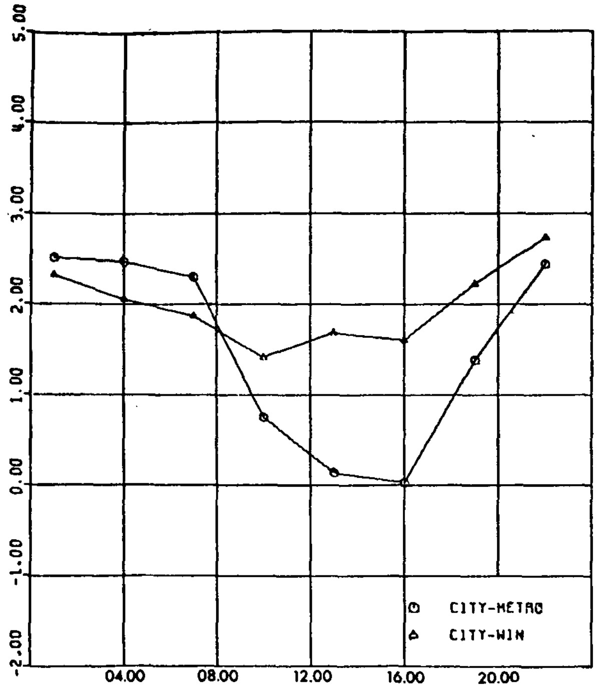

FIG. 4. Variation of temperature differences with time of day, e.g., the value for City-Metro for 0100 is the average of 365×10 (3650) temperature differences.

The monthly variation of the same two rural-urban temperature differences (the daily average of the eight readings) appears in Fig. 3. Similar trends of both lines indicate a minimum difference in January–March and a maximum in August–October. The causes for this seasonal variation can only be suggested at the present time. Sundborg (1950) in Sweden related urban-rural temperature differences to temperature, wind speed, vapor pressure and sky cover in an empirical equation, derived from a multiple regression analysis. His equation was tested for January and July on the Detroit-Windsor data, and it was found that sky cover was the most significant factor, decreasing the temperature difference in both winter and summer as cloudiness increased and solar radiation income was decreased. Monthly normal cloud statistics for the Windsor airport show a pattern similar to that of Fig. 3 with January the month of highest cloud cover, 7.5 (tenths), and August the month of least cloud cover, 4.8 (tenths). Certainly the heat added to the atmosphere by central heating in the Detroit-Windsor area does not result in the largest urban-rural temperature difference in winter as it does in Toronto, where Thomas (1971) reported the greatest such temperature difference to be 4F just before dawn in winter.

The variation of mean difference with time of day is seen in Fig. 4 (the average of the hourly readings for the 10-year period). This is the pattern found in most urban heat island studies, with a maximum in the early hours (2.5F) and a minimum at mid-day (1.5 for City-Windsor; almost zero for City-Metro). The difference between the two rural sites cannot be explained. It might have been assumed that the prevailing westerly winds would result in a lesser temperature difference between the City and Windsor airports than between the City and Metro airports; yet the reverse is true for the greater part of the day. An explanation may lie in the position of the airports with respect to Lake Erie and Lake St. Clair.

The hourly variation of the heat island for February (Fig. 5) shows the existence of a "cold island" in Detroit between 0900 and 1600. Such a cold island may be due to the reduction of incoming solar radiation in the urban area by a pollution dome and the low sun angle or some mesoclimatic effect. Thomas reported for Toronto that "cold islands" occurred in the summer months of May–August from about 0800–1400. He attributes this deficit to urban reduction of bright sunshine and radiation but why such reduction results in cold islands in summer in Toronto and winter in Windsor is unclear. An explanation might be the lake breeze effect in Toronto with lake temperatures colder than land in summer; but the explanation for Windsor is not known.

Although the magnitude of some urban-rural differences is probably underestimated in the present study, and it is realized that the climate of a city has many microclimate components, the variability of the urban heat island in Detroit-Windsor has been described. Since both the City-Metro and City-Windsor tem-

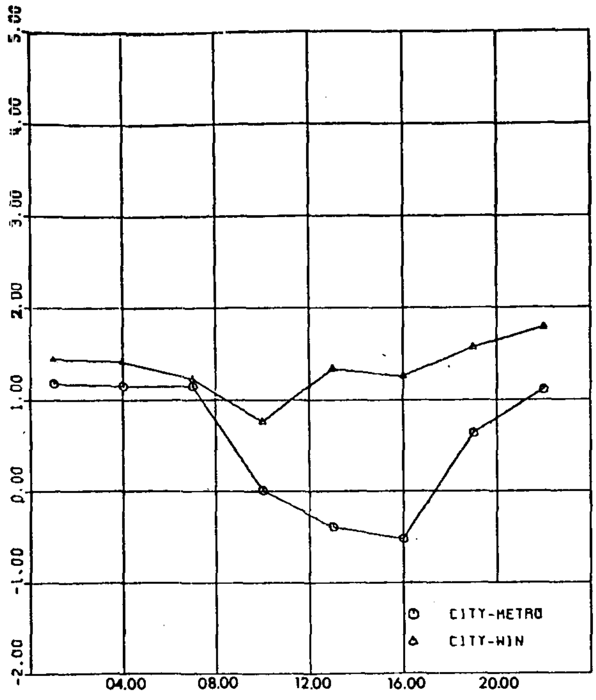

FIG. 5. Variation of temperature differences with time of day for February. Each data point represents 28×10 (280) temperature differences.

perature differences show the same seasonal trends, with highest differences in autumn, lowest in winter, this appears to be a phenomenon peculiar to the Detroit-Windsor urban climate. Further study must determine if radiation differences or mesoclimatic factors or a combination of both cause these seasonal differences.

3. Observed winter atmospheric transmissivity ratios

Urban climatologists agree that a city's effect on the energy balance is a complex phenomenon. Climatologists in many cities throughout the world are measuring both short- and longwave parameters, but results are often contradictory and the overall energy balance picture is still far from clear (Peterson, 1970).

It is generally agreed, however, that because of pollution in the urban atmosphere, the radiation income in a city is reduced from that received by the adjacent countryside. Landsberg estimated that the total radiation over most cities is reduced by about 15%, usually more in winter and less in summer. Treating incoming solar (total global) radiation only, Emslie (1964) found that the downtown Toronto area received from 5–10% less radiation annually than suburban Scarborough. In Montreal, East (1968) reported that the average rural-urban difference was 9%.

Transmissivity ratios have also been analyzed as a measure of reduction of incoming solar radiation if continuously recording instruments at the rural and urban sites are not available. This ratio is a measure of the transparency of the atmosphere to solar radiation: actually, the ratio of the amount of solar radiation received on a horizontal surface at the earth's surface, to that received at the top of atmosphere. It is a dimensionless unit ranging from 0 to 1. Nishizaiva and Yamashita (1967) found that transmissivity ratios for clear days in Tokyo averaged 0.5–0.7 over the year; while at rural Kumagaya, 50 km distant, the ratios were 0.7–0.8. In a polluted atmosphere, the absorption and scattering of radiation becomes very complex. It has been found that particulate matter in the atmosphere is an efficient absorber of incoming solar radiation. This absorption with some backscattering results in the attenuation of the solar beam. In contrast, the main atmospheric pollutants, such as suplhur dioxide, carbon monoxide and carbon dioxide (with the exception of nitric oxide), do not add significantly to the absorption of radiation in the solar spectrum. Water vapor is the only gaseous constituent of the atmosphere that is able to effectively reduce the solar radiation income by scattering part of the direct beam, some of which is lost to space. It is theorized then that the dust dome, or pollution haze over a city, attenuates incoming solar radiation and that this attenuation should be greatest for high-latitude cities when the sun's elevation is low, that is, in winter.

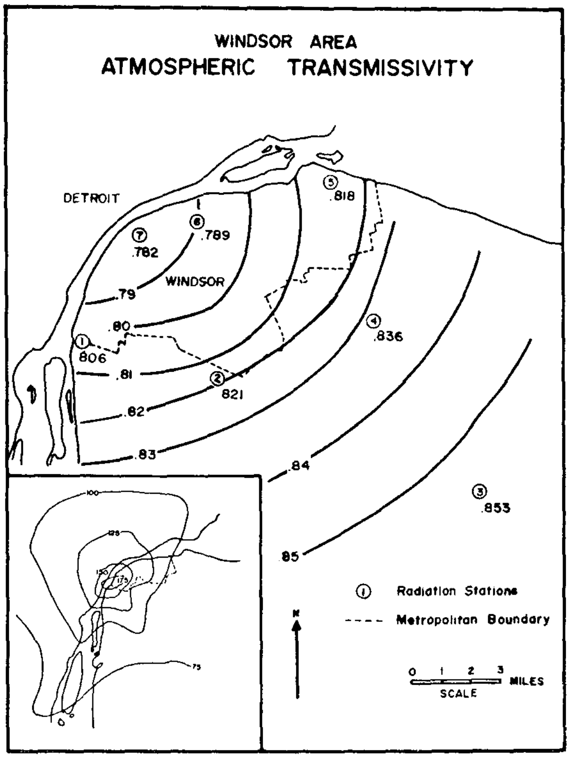

Fig. 6. Average atmospheric transmissivity in the Windsor area for the nine periods of observation (clear, winter days). Inset map shows particulate concentrations ($\mu g\ m^{-3}$) from International Joint Commission report.

To estimate the reduction of winter solar radiation in Windsor, it was decided to measure solar radiation at seven selected sites in the area during the winter of 1970–71 on clear days, and to convert these readings to transmissivity ratios. The effect of water vapor, in this study, was minimized by taking measurements only on cold, dry, clear days when the area experienced anticyclonic weather conditions, and the vapor pressure averaged 2.9 mb.

Incoming solar radiation was measured with a Kipp and Zonen pyranometer which is sensitive to wavelengths from 0.3–2 μm. The instrument was mounted on a camera tripod and connected to a portable indicator calibrated by C. W. Thornthwaite Associates. The scale is read in langleys per minute. A check on the accuracy of the instrument was further provided by comparison, each day of measurement, with an Eppley pyranometer which had been calibrated by the Atmospheric Environment Service Laboratory. The difference between the readings was never more than 3%. The seven sites selected are shown in Fig. 6 (1, 7, 6 and 5 were urban locations; 2 and 4 suburban; and 3 rural). All were in open areas, such as an open park or schoolground, to eliminate reflection and shadow from buildings. Measurements were taken on nine clear days (weekdays) from 2 December to 4 March between 0900 and 1400, and values converted into atmospheric trans-

TABLE 2. Atmospheric transmissivities.

	Observation sites								
Day	1 Ojibway Mine	2 Veterans Park	3 Essex District High School	4 Fairplay Public School	5 Windsor Tecumseh Filtration Plant	6 Wigle Park	7 University of Windsor	$\bar{X}$	Wind*
1	0.81	0.83	0.83	0.79	0.80	0.75	0.73	0.79	WSW 12
2	0.80	0.87	0.87	0.79	0.75	0.65	0.68	0.77	SW 3
3	0.84	0.83	0.88	0.86	0.84	0.83	0.84	0.85	SW 17
4	0.81	0.86	0.86	0.85	0.84	0.82	0.82	0.84	S 6
5	0.82	0.82	0.86	0.85	0.85	0.82	0.81	0.83	NW 16
6	0.77	0.85	0.87	0.87	0.86	0.82	0.81	0.84	N 12
7	0.79	0.80	0.88	0.88	0.80	0.80	0.75	0.81	SW 18
8	0.82	0.74	0.83	0.84	0.85	0.83	0.82	0.82	W 15
9	0.79	0.79	0.80	0.79	0.77	0.78	0.78	0.79	WNW 24
Average	0.806	0.821	0.853	0.836	0.818	0.789	0.782		

* Wind speed and direction for time of measurement obtained from the Meteorological Office, Windsor Airport.

missivity ratios (Table 2). The conversion to transmissivity ratios was made possible by the use of a computer program to estimate values of solar radiation on a horizontal area at the top of the atmosphere for the Windsor area.

Fig. 6 shows the average atmospheric transmissivity in the Windsor area for the nine days. The lowest value of 0.78 is for the University of Windsor site and the highest (0.85) for Essex, a difference of 9%, similar to the differences obtained by Emslie and East. For comparison, average particulate matter in the atmosphere in the Detroit-Windsor area from the International Joint Commission Report is shown in the inset map. There is a remarkable similarity between the areas of high concentrations of particulate matter and the areas of lowered transmissivity.

It is noted from Table 2 that average atmospheric transmissivities were also variable from day to day. If it is assumed that the amount of pollution emitted into the atmosphere in the Detroit-Windsor area during weekdays is constant, the variation is probably due to wind speed and direction. Wind direction is particularly important when most of the particulates originate from a single or few large sources. Such is the case in Windsor where the major source of particulates are the steel and power plants in Detroit to the southwest of sites 1 and 7. The nine-day sample is too small to permit an analysis of the relationship between wind speed and direction and transmissivity, but a relationship can be observed. On day 2, with a southwest wind of only 3 mph, there was the greatest rural-urban difference in transmissivity (25%). On days with high wind speeds, such as day 3 (17 mph) or day 9 (24 mph), the urban-rural transmissivity difference was only 4–6%. Also, it is seen from Table 2 that the wind in all cases was from 180° to 360°. Winds blow from these directions about 75% of the time in the Windsor area. During the remaining 25% of the time, with the wind blowing from the easterly direction, transmissivity ratios should increase.

The lowest ratio observed was 0.65 on a day when pollution appeared visibly high. Since extremely small amounts of water vapor were present in the atmosphere, this means that dust or particulate matter caused a 35% reduction in incoming solar radiation in the western parts of the city. Since there was almost no wind, this condition was extremely localized; 10 mi to the east, the transmissivity ratio was 0.87. The Windsor urban ratios were not as low as the urban winter ratios for Tokyo (0.5) nor were the rural ratios as low as those for Kumagaya (0.7–0.8). Presumably, the difference could be due to a more polluted atmosphere or to a higher water vapor content in Japan.

The research on spatial variation of transmissivity ratios as well as on incoming solar radiation and net radiation is being continued for other seasons of the year for clear days. Also, monitoring of incoming solar and net radiation is continuing. Only by such measurement can it be determined by how much man is indeed altering the urban radiation climate and if air pollution legislation is effective.

4. The effect of the city on urban seasonal precipitation

In his oft-quoted table of average changes in climatic elements caused by urbanization, Landsberg states that urban precipitation totals average annually 5–10% more than those of the neighboring rural environment. This increase is usually attributed to the abundant supply of condensation nuclei and increased convection due to the heat island influence in the urban atmosphere. Research on the effect of the urban area on precipitation patterns has been inadequate because of the lack of proper precipitation networks, and the difficulty of separating the influence of city location from effects of the city itself. In a recent review of urban effects on precipitation in the United States, Changnon (1969) stated that if topographic effects are eliminated, urban-produced increases in annual precipitation have been found to be from 5–8%. In the mid-western cities of Chicago, Champaign-Urbana and Tulsa, warmer half-year precipitation totals were 4–6% higher in urban than rural areas; while for the colder half-year, the values were 6–11%. Huff and Changnon (1972) report that for St. Louis, urban effects caused an increase in precipitation in and downwind of the city in all seasons, and that the average summer rainfall was increased 6–15% for distances up to 25 mi downwind of the city. The controversial LaPorte data, with differences reported as 30–33% for warm and cold season precipitation, perhaps should be considered a special case. Thomas reports that in Toronto, with 35 precipitation observing stations, many in operation for 10–15 years, no urban effect on precipitation has been discovered.

In the present study for Detroit-Windsor, an attempt is made to assess the effect of the urban complex on seasonal precipitation amounts in the city. This is done by a comparison of the regional season precipitation patterns for southeast Michigan, assuming there is no city, with urban area or microscale precipitation patterns, using data from the SEMCOG[6] network of stations in the three-county area of Wayne, Oakland and Macomb. The common period used was 1961–69 since the SEMCOG network was begun in 1961, with 42 stations having an acceptable 9-year record (Table 3 and Fig. 7). The regional precipitation stations, also listed in Table 3 and shown in Fig. 7, include five Canadian stations, although it is realized that two of these (Harrow and Leamington) are less than 25 mi downwind from the city center and perhaps have urban-induced precipitation patterns. There is also the problem of comparability of data. The American precipitation gage measures both rain and snow, is 31 inches tall, and has an orifice 8 inches in diameter. The Canadian stations record rainfall with a gage 3.4 inches in diameter with its orifice 12 inches above ground, and snow is measured with a ruler and converted to rainfall equivalent by dividing by a factor of 10. It is not known if the resulting precipitation data are comparable. However, present discussion will be limited to the Michigan situation, since the 9-year data are available only for Michigan stations. In 1970, the University of Windsor installed 18 gages in and near the city of Windsor, so future analysis will include Windsor and the downwind precipitation effects.

The gages of the SEMCOG network are the weighing, recording Belfort type. Fifteen-minute precipitation amounts can be read with an accuracy of 0.02 inch. Again the question of comparability of data from the official American and the Belfort gages can be raised. At the University of Windsor weather station, the two gages have been in operation for 20 months. For the total period of record, the Belfort gage recorded 2% less precipitation than the standard American gage. Seasonally, the difference seemed random, from 5% more for the Belfort gage in summer, to 9% less in

TABLE 3. Average monthly precipitation (1961–69) for the regional and SEMCOG stations (inches).

Station	Winter*	Spring*	Summer*	Fall*	Annual
		Regional stations			
1. Alma	1.46	2.60	2.87	2.50	28.29
2. Adrian	1.95	2.83	3.48	2.34	31.80
3. Ann Arbor	1.77	2.61	3.36	2.07	29.43
4. Bay City	1.26	2.60	2.73	2.45	27.12
5. Charlotte	1.85	2.79	3.19	2.65	31.47
6. Hillsdale	2.38	3.39	3.74	2.78	36.87
7. Jackson	1.38	2.58	3.28	1.85	27.27
8. Lansing	1.64	2.37	3.19	2.25	28.25
9. Lapeer	1.31	2.29	3.01	2.05	25.98
10. Midland	1.86	2.63	2.87	2.41	29.31
11. Milford	1.84	2.60	3.53	2.06	30.09
12. Monroe	1.94	2.72	3.15	2.26	30.21
13. Owasso	1.56	2.40	2.98	2.30	27.72
14. Port Huron	1.69	2.62	3.47	2.39	31.51
15. Saint Johns	1.46	2.57	3.06	2.47	29.68
16. Sandusky	1.47	2.15	3.16	2.29	27.21
17. Chatham	2.44	2.73	3.56	2.15	32.64
19. Harrow	2.55	2.99	3.40	2.34	33.87
20. Leamington	2.41	2.83	3.34	2.24	32.46
21. Sarnia	2.31	2.74	3.33	2.31	31.97
22. Woodslee	2.32	2.65	3.75	2.23	32.85
		SEMCOG stations			
M-3	1.77	2.45	3.52	1.88	28.86
O-1	1.30	2.70	3.48	1.75	27.69
O-2	1.63	2.60	3.07	1.86	27.48
O-3	1.36	2.48	3.11	1.90	26.55
O-4	—	—	3.20	1.80	—
O-5	1.24	2.33	2.97	1.78	24.96
O-6	1.97	2.75	3.42	1.96	30.30
O-7	1.70	2.41	3.37	1.82	27.75
O-8	1.54	2.76	3.26	2.18	29.22
O-9	1.68	2.51	2.80	1.97	26.88
O-10	—	2.81	3.32	2.12	—
O-11	1.71	2.71	3.90	2.24	31.68
O-12	1.52	2.34	3.31	2.05	27.66
O-13	1.58	2.59	3.04	1.91	27.36
O-14	1.77	2.80	3.12	2.04	29.19
O-17	1.74	2.46	3.40	1.73	27.99
O-18	1.70	2.36	3.32	1.79	27.51
O-19	1.64	2.72	3.38	1.84	28.74
O-20	—	—	3.17	1.68	—
O-21	—	—	2.78	1.78	—
W-1	2.04	3.51	4.06	2.35	35.88
W-2	2.41	3.62	4.10	2.39	37.56
W-3	—	—	3.69	—	—
W-4	—	—	2.91	1.48	—
W-5	1.57	2.23	2.76	1.71	24.81
W-8	2.17	3.48	4.41	2.58	37.92
W-9	1.75	2.53	3.15	1.84	27.81
W-12	—	2.07	3.32	1.49	—
W-13	1.97	2.54	3.67	2.19	31.11
W-14	1.82	2.26	3.56	1.96	28.80
W-15	1.90	2.27	3.64	1.87	29.04
W-16	2.00	3.14	4.10	2.30	34.62
W-17	—	—	2.97	1.61	—
W-18	1.89	2.73	3.54	1.94	30.30
W-19	—	—	3.71	—	—
W-20	1.54	2.56	3.84	1.86	29.40
W-21	2.01	2.73	3.80	1.99	31.59
W-22	1.46	2.51	3.52	1.83	27.96
W-23	1.81	2.68	3.45	1.88	29.46
W-24	2.05	2.73	3.77	2.06	31.83
W-25	1.94	2.73	3.73	1.97	31.11
W-26	2.10	2.68	3.59	1.98	31.05

* Winter, December–February; spring, March–May; summer, June–August; fall, September–November.

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[6] South Eastern Michigan Council of Governments; precipitation data supplied by Norton Strommen, State Climatologist for Michigan.

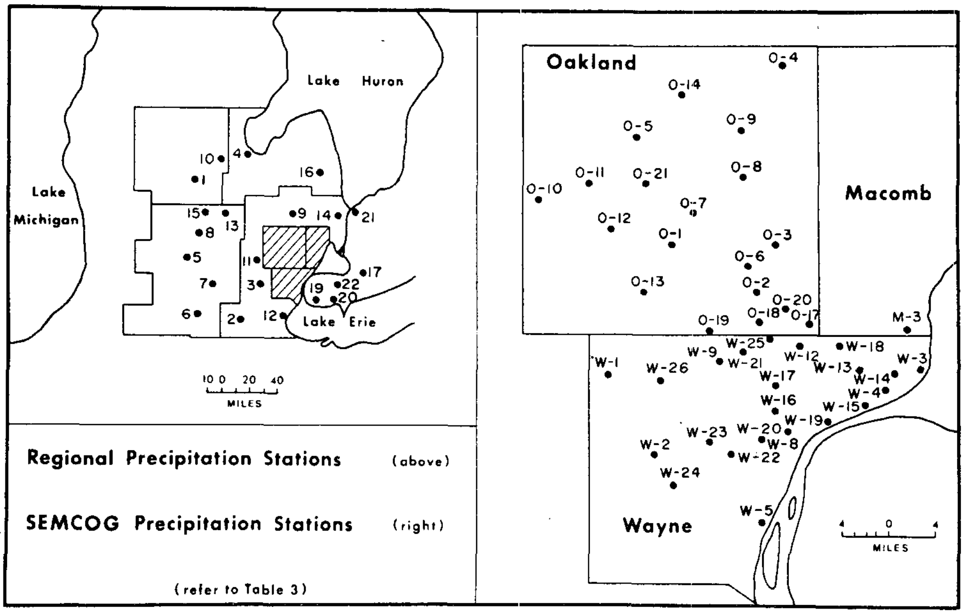

FIG. 7. The study area showing locations of the 21 regional climatic stations and the 42 SEMCOG stations.

spring and no difference in fall. It is assumed for the 9-year average seasonal value used in the present study, that the data are comparable. The regional patterns of annual and seasonal precipitation as well as the micro-scale precipitation patterns are shown in Fig. 8.

In the present study, visual comparison is made between the regional and SEMCOG precipitation patterns. In the map showing annual total precipitation, the gradient is from low values in the Saginaw Bay area (<28 inches) to about 32 inches in southeastern Michigan. The 30-inch isohyet appears to bisect the city. The annual average micro-pattern of precipitation for the three-county area (Fig. 8) appears to agree with the regional pattern. In the northern urban areas, values are again 28–30 inches and in the central areas, 30–32 inches. However, along Lake St. Clair and the Detroit River, including the central business and industrial areas, the annual amounts are less than 30 inches, differing from the regional precipitation pattern. Annual precipitation in the Detroit urban area does not seem to follow the rule that urban precipitation is 5–10% higher than rural.

The seasonal maps in Fig. 8 show the average precipitation in inches per month. Winter precipitation amounts are much less than for other seasons in this area of Michigan, varying from 1.50 inches in the Saginaw Bay area to 2.00 inches at the western end of Lake Erie. The 1.75-inch isohyet appears to bisect the city. The microscale precipitation pattern shows the situation that is expected for most of the three-county area, with the exception of the industrial areas in the south of Wayne County where 1.75 rather than 2.00 inches is recorded. In spring, the regional gradient is again from northwest to southeast, from 2.50 to 3.00 inches, the urban area appearing to lie between the 2.50- and 2.75-inch isohyets. The large-scale pattern is generally similar to that of the Detroit urban area, with 2.50–2.75 inches. In summer, the regional gradient is in the same direction, with the monthly precipitation now ranging from 3.00 inches in the northwest to 3.50 inches in the southeast, with the city apparently in the 3.25–3.50 inch range. However, the regional pattern indicates that most of Wayne County averaged more than 3.50 inches, with islands of 3.75 to more than 4.00 inches (increases of 4–22% over the regional precipitation amounts). The regional pattern for fall shows most of southeastern Michigan to have 2.00–2.25 inches of precipitation. The pattern for the three-county area, however, indicates that most of the urban areas received less than the amount expected, i.e., from 1.75–2.00 inches.

This preliminary study of the effect of the city of Detroit on precipitation amounts indicates that annual and spring regional and microscale precipitation maps are similar, that during the fall and winter the city seems to have less precipitation than the surrounding areas, but that in summer, the city receives up to 20% more precipitation than regional patterns indicate. This corroborates Strommen's findings that there is more warm weather thunderstorm precipitation in the city than in the rural areas. The present study indicates that seasonal precipitation in Detroit does not follow the trends found in other mid-western cities, i.e., of 4–6% increase over rural areas in warm months and 6–11% in cold months. However, how much of the differences are due to urban effects and how much to the

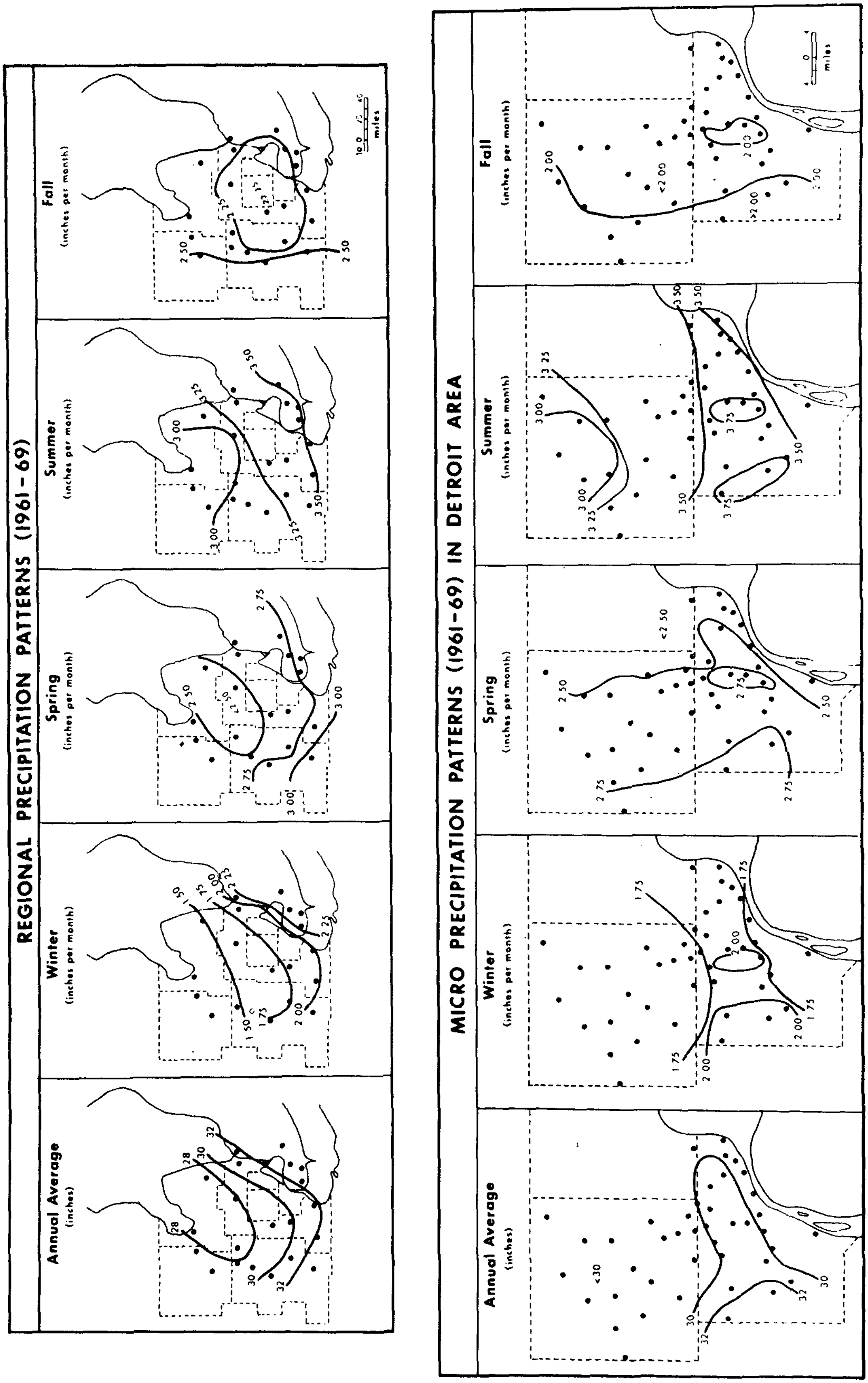

FIG. 8. Regional precipitation patterns, annual and seasonal, in southeastern Michigan and southwestern Ontario (top) and microscale precipitation patterns (from SEMCOG data) in Detroit area (bottom).

lake effect is unknown. Certainly the season of maximum heat island development, i.e., fall, does not appear as a season of increased urban precipitation.

5. Summary

A 10-year study of the urban-rural temperature differences at 3-hr intervals at the three airports in the Detroit-Windsor area showed an average urban-rural difference of 1.5–2.0F. Maximum differences were observed in August–October and minimum differences in January–March. Diurnally, an average maximum difference of 2F occurred in the early morning hours and a minimum or zero difference at midday.

Atmospheric transmissivity ratios during clear winter days in urban Windsor averaged 9% less, and under calm conditions reached 25% less, than in adjacent rural areas.

Annual precipitation averages in the Detroit urban area did not appear to differ from regional values. However, seasonal precipitation amounts seem to be changed by the presence of the city. In autumn and winter, Detroit receives less precipitation than the surrounding rural areas and in summer about 20% more.

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