MICROMETEOROLOGICAL OBSERVATIONS IN AN AREA OF URBAN GROWTH*

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Abstract. Stationary and mobile surveys of micrometeorological changes in the new town of Columbia, Maryland have been made since late 1967. These show the development, intensification, and expansion of an urban heat island. This phenomenon is principally attributable to the altered heat flux into and out of the soil caused by the change in surface characteristics. About half of the observed change of relative humidity can be assigned to decreased evapotranspiration as a result of replacing vegetation by stone and asphalt.

1. Introduction

In the corridor between Washington, D. C., and Baltimore, Maryland – two cities about 50 km apart – a new town was started in 1967. Located about 21 km WSW of Baltimore, Columbia had about two hundred inhabitants at that time. The terrain is slightly rolling with maximum elevation differences of 53 m in the town site. It was originally farmland, interspersed with extended wood lots. The town rapidly grew to 10000 people by 1970 and is projected to have a population of 100000 in 1985 on an area of 28 km^2. An intensive meteorological survey was started with the incipience of the building program. Special emphasis was placed on the core area of 2 km^2, which has been kept under close surveillance by stationary and mobile surface observations, supplemented by occasional low-level flights. The purpose of these observations was to document micrometeorological changes, if any, and compare these with urban meteorological influences surmised in the literature by comparisons of observations inside and outside of existing cities. Although the town is far from having attained its ultimate size, measurable changes have already occurred and some of this information is reported here and in more detail elsewhere (Maisel, 1971). Figure 1 shows portions of the site as of 1970 and the general landscape.

2. Observations

Stationary observations were made over the three-year period 1968–1970 with MRI mechanical weather stations which furnished continuous records of temperature and the wind vector at suitable sites. A large series of mobile surveys of temperature, humidity and wind at 2 m were made. Sampling took place at 17 spots in various stages of development, from a totally rural setting to the completely urbanized

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Fig. 1. Aerial photograph of NW sector of Columbia, Maryland (September 1970). One of the centers of the heat island, shown in Figures 2 and 3, is the shopping center marked by an arrow. Distant background shows character of undisturbed landscape.

shopping center. Infrared measurements of surface temperatures of various types of surfaces were taken with a Barnes infrared thermometer. On suitable occasions wind speeds were measured with a portable mast at two or three levels to obtain estimates of the roughness parameter. Also, the various components of the radiative fluxes were measured in different settings with radiometers.

3. Results

A. SURFACE ROUGHNESS

Changes took place very rapidly in the boundary layer of the sector that became urbanized. It is not very surprising that erection of dwellings in areas that had been fields increased the roughness parameter z_0 by over an order of magnitude from a few centimeters to about one meter.

B. THERMAL BALANCE

It is not really astonishing, either, that the replacement of the vegetative cover with pavements radically changed the nature of the thermal balance at and near the surface. Table I shows a typical set of data, giving the elements of the heat balance for daytime and for two night observations on a clear near-equinoctial day with very little wind, for two sites. One of them was an undisturbed weed field and the other the parking lot in a shopping center, about 600 m apart.

The essential facts to be noted are: (1) the much higher surface temperatures of the parking lot, compared to the field, – a condition that prevailed throughout the night; (2) the negligible effect of this condition on the air temperature in daytime, but the rather warmer air over the parking lot than over the weed field at night, – very pronounced at midnight and still measurable before sunrise; (3) the much larger values of the heat flux into and out of the ground in the parking lot, that is at noon 2.7 times larger than in the field. This latter condition is the essential element of the urban heat island. During this set of measurements there was no internal heating of dwellings yet and there were no industrial heat emissions in Columbia. The heat resulting from the metabolism of the inhabitants and traffic was about two orders of magnitude below the exchange of natural radiative fluxes at the surface. It had already been shown that under suitable synoptic conditions, a single block of buildings will create a miniature heat island (Landsberg, 1970). We can, therefore, tag the man-made change of the surface as the primary cause of the heat island, a conclusion that has been reached also by East (1971) from his observations in the entirely different setting of Montreal.

C. HEAT ISLAND

It is interesting to watch the Columbia, Maryland, heat island grow and intensify as the town expands. This can perhaps be best illustrated by isotherm maps for two evening surveys, a little over an hour after sunset, when on the average the heat island shows the maximum difference with respect to the undisturbed countryside. One of these (Figure 2) was based on mobile observations in 1968, when only a small sector of the town was developed; the other (Figure 3), on data gathered in 1970. The syn-

TABLE I

Elements of heat balance in Columbia town area

	T_A	T_S °C	Q_I	$Q_L\downarrow$	$Q_L\uparrow$	Q_{LE}	Q_H	Q_S	cal cm^{-2} min^{-1}
Time 12 h									
Weed Field	24.7	32.0	1.20	0.43	0.67	0.30	0.12	0.24	
Parking Lot	24.7	47.5	1.23	0.43	0.85	0.00	0.10	0.64	
	T_A	T_S °C	Q_N	$Q_L\downarrow$	$Q_L\uparrow$			Q_S	cal cm^{-2} min^{-1}
Time 00 h									
Weed Field	12.7	15.5	−0.10	0.41	0.54			−0.13	
Parking Lot	15.0	21.5	−0.12	0.41	0.61			−0.20	
Time 05 h									
Weed Field	12.2	11.0	−0.09	0.40	0.50			−0.10	
Parking Lot	12.7	18.0	−0.13	0.41	0.57			−0.16	

Symbols: T_A air temperature (2 m); T_S surface temperature; Q_I incoming radiation; $Q_L\uparrow$, $Q_L\downarrow$ upward and downward long-wave radiation respectively; Q_{LE} heat loss by evaporation; Q_H advected heat; Q_S surface heat flux; Q_N net radiation.

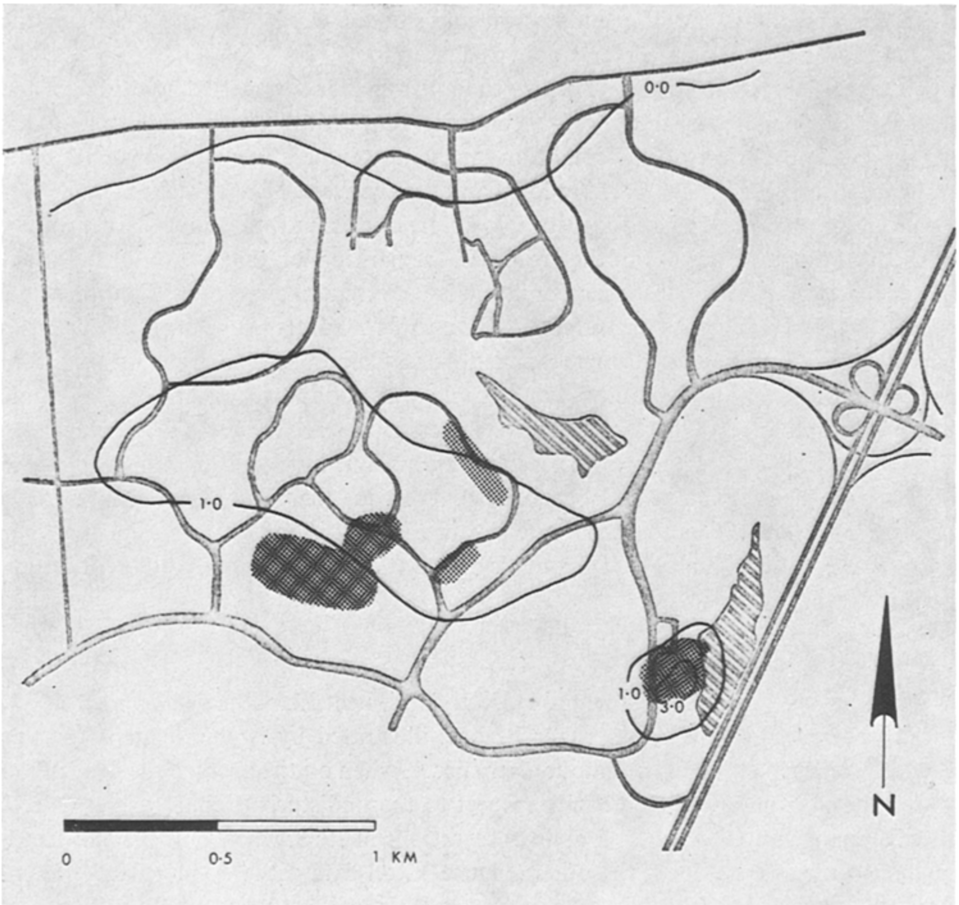

Fig. 2. Isotherms (°C) of temperature departures against rural control point in Columbia, Maryland, town sector. Observations were taken on a clear, calm evening one hour after sunset in August 1968 and show an incipient heat island.

Hatching - Stripes: two man-made lakes; – light stippling: moderate urbanization (single houses and garden apartments); – dark stippling: intense urbanization (business buildings, shopping centers, parking lots).

optic situations, with very low surface wind speeds were nearly identical. In the earlier case only a weak general heat island of 0.5 °C with two small cores, in the business district and a shopping center, existed. In the later year the heat island encompassed a much larger area. The same cores existed, with 4.5 °C temperature excess over the countryside and a 2 °C surplus isotherm enclosing a then much more densely built-up sizeable area. In midday, as many earlier studies elsewhere have shown, the heat island was only about 1 °C because of the equalizing effects of convective and advective air flow.

D. RELATIVE HUMIDITY

A large number of relative humidity measurements were made during the mobile

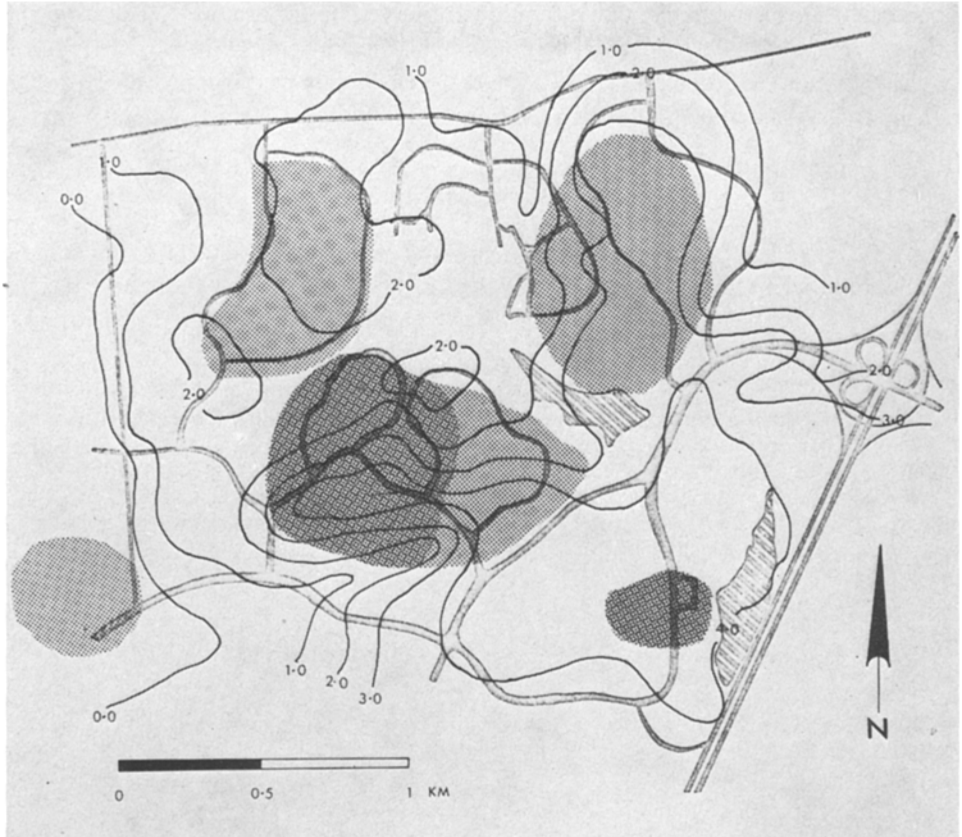

Fig. 3. Temperature departures on a clear, calm evening, one hour after sunset in early September 1970, showing a greatly intensified heat island, corresponding to growth of the town. (Notation as in Figure 2).

surveys. These showed an overall average decrease of 4% in relative humidity during daytime in the built-up area over a three-year interval of town growth. The nocturnal data are as yet inadequate to establish a trend. In 1970 the vapor pressure decreased, on an average by 0.7 mb from the rural environs to the most urbanized area.

Simple considerations show that about half of the reduction in relative humidity is attributable to the temperature rise and the other half to reduced evapotranspiration. The efforts of the developers to preserve some trees and green surfaces were not sufficient to overcome the overwhelming effect of paved and shingled surfaces, which are so characteristic of modern high-density land utilization for settlements.

4. Conclusion

Urbanization, even in early stages, rapidly leads to the development of a heat island, caused by the alteration of the physical characteristics of the surface. It is the governing element in the microclimatic alterations observed in urban areas, aside from the changes in the atmospheric composition not discussed here. Only a rather radical redesign of human settlements could obviate the changes in heat balance, temperature, and humidity observed in all urban environments.

Acknowledgement

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