

Nocturnal Temperatures in Edmonton, Alberta¹

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ABSTRACT

A network of seven thermographs has been operated continuously within the city of Edmonton, Alberta, since February 1968 by Geoscience Research Associates, Ltd., under contract to the Department of Health of the Government of Alberta. Data from these stations, together with hourly observations from two rural airports and one urban airport in the Edmonton area, are inadequate for mapping the temperature field, but provide an unusual opportunity for the study of some climatological characteristics of urban temperatures over relatively flat terrain undisturbed by lake or sea influences. Annual variations in maximum heat island intensity based on monthly mean data are ill-defined because of large variations in month-to-month frequencies of favorable nights. Stratified monthly samples consisting only of nights with intense heat islands show weak annual maxima in January and June. A well-defined diurnal cycle in heat island intensity is found with a maximum 3–4 hr after sunset in all seasons. The time of maximum heat island intensity precedes the time of maximum vertical temperature gradient over the city in all seasons. In the presence of strong vertical wind shear, inversion breakdowns occur and these are found to be patchy and of small horizontal extent.

1. Introduction

In attempting to model the urban heat island it is usually desirable, and indeed necessary, to begin with drastic simplifications of the problem. Data on the climatological properties of observed heat islands under conditions favorable to their development can be helpful in formulating and testing models. Unfortunately, although numerous studies of the climatological properties of urban heat islands have been reported for many different regions, the results are somewhat conflicting. While it is generally conceded that the annual cycle of heat island intensity is weak, results differ concerning the timing of maximum and minimum intensities (Kratzer, 1956). Maximum heat island intensities occur at night, but again results differ concerning the time of peak intensity relative to local sunrise and sunset (Landsberg, 1969; Chandler, 1965). Even if factors such as instrumental errors or unrepresentative sites are disregarded, it is not difficult to find reasons for some of these differences. Local seasonal and diurnal variations in wind direction relative to nearby water bodies, or seasonal and diurnal variations in cloudiness and wind speed, for example, will influence both the frequency and intensity of urban heat islands, and such influences will be reflected in monthly mean urban-rural temperature differences. In an attempt to minimize topographic and large-scale meteorological effects of this nature, annual and diurnal heat island intensity variations were analyzed for Edmonton using only

those days most favorable for strong heat island development.

2. Data sources

The city of Edmonton (53°33'N, 113°30'W) is located on the banks of the North Saskatchewan River in central Alberta. Fig. 1 shows limits of the built-up areas in 1968 and the principal topographic features of the region. The river valley is steep-sided and narrow with an average depth of about 50 m. Away from the main river valley and ravines elevations change most rapidly to the southeast with a rise of about 80 m in a distance of 15 km from the city center. Broadly speaking, the city consists of a medium-density core surrounded by low-density alternating commercial and residential areas. Heavy industries are confined almost entirely to the eastern outskirts near the river valley.

Surface temperature data were obtained from seven shielded bimetal thermographs at numbered locations within the city (Fig. 1), from the Edmonton Industrial Airport (XD) about 3 km northwest of the city center, and from the Edmonton International Airport (EG) about 26 km south-southwest of the city center. Airport temperatures were measured with mercury thermometers in ventilated Stevenson screens. Vertical temperature differences were obtained from shielded, aspirated electrical resistance thermometers mounted on booms at 17 and 112 m extending from the north face of the CN Tower building in the city center (T in Fig. 1). Conventional hourly airways observations of cloudiness, visibility, wind, precipitation, and other

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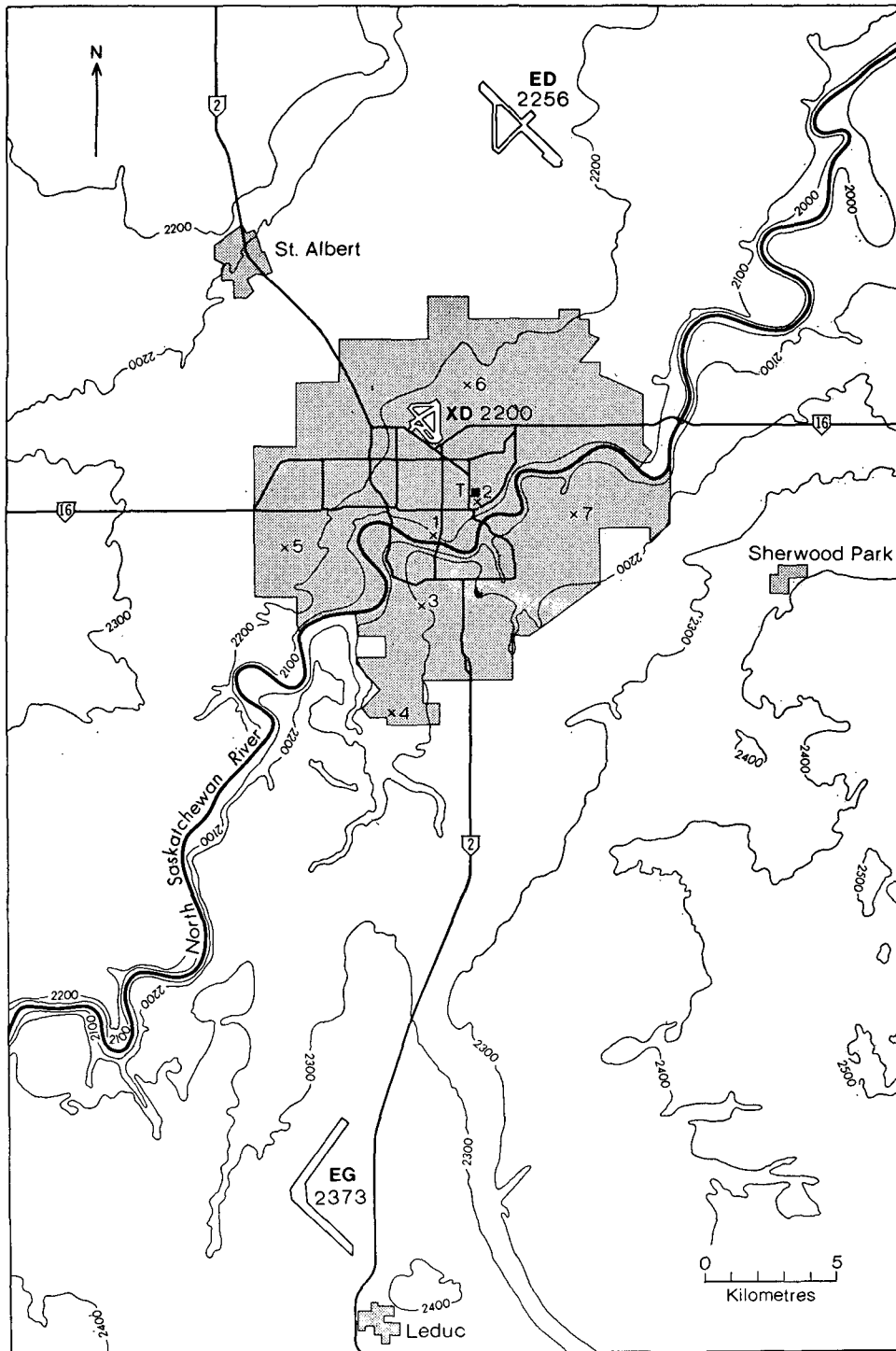


Fig. 1. Map of Edmonton, Alberta, and vicinity.

elements were available for all three airports shown in Fig. 1. Operation, maintenance, and calibration of the thermographs and CN Tower instruments were performed by Geoscience Research Associates, Ltd., of Edmonton, under contract to the Department of

Health of the Government of Alberta. Airport weather data were supplied by the Atmospheric Environment Service of the Department of the Environment. The thermographs were mounted on steel posts at a height of 1.5 m above grass surfaces. All thermographs were

calibrated at a common site prior to installation and this was followed by weekly calibration checks with a portable aspirated psychrometer. The thermograph screen and natural ventilation were found to be inadequate at times in direct sunlight. The possibility of nighttime radiation errors due to nearby buildings was investigated by varying the distances of separation between building walls and the thermograph at one of the suburban stations. Measurable influences were found at 2 m but not at the final separation distances of 10 m or more. Because of uncertainties in routine calibration on sunny days additional calibration checks were made during periods of continuous precipitation and strong winds. In such periods (of duration ≥ 6 hr) the mean urban airport (XD) temperature exceeded the rural airport (EG) temperature by $0.3\text{C} (\pm 0.4\text{C})$. For purposes of calibration this result was used to justify equating all thermograph readings to the mean urban airport temperature in such periods with the expectation that systematic errors would be reduced to $\leq 0.5\text{C}$.

3. Annual cycle

The average horizontal temperature difference between the city center and the suburban thermograph stations was used as an estimate of the urban heat island intensity. Only nighttime thermograph observations were accepted because of direct solar radiation errors. Averages were computed using data from XD (central), and thermograph stations 4 (south), 5 (west), 6 (north) and 7 (east). The urban airport XD was used as a central station because of the sensitivity of intensity values to central station readings and because of the unknown magnitude of nighttime radiation errors at station 2 located near very large buildings. It is known from comparisons with auto traverse data and with nearby CN Tower data that such errors do not exceed 1C . However, non-systematic errors of this magnitude are unacceptable in studying the annual cycle. Cumulative intensities were calculated for alternate hours each night, and from these data the three most intense heat islands were selected for each month in the two-year period. In addition, temperature differences between the urban and rural airports were obtained for the same nights for comparison purposes.

The three month-running means of the largest urban-rural temperature differences on the three most intense heat island nights in each month for the period March 1968 to March 1970 are shown in Fig. 2. The airport differences (XD-EG) were much larger than the urban airport-suburban station differences because the rural airport was well beyond the urban heat island and almost always upwind of the city on strong heat island nights. It is clear from Fig. 2 that the annual cycle of heat island intensities was of small amplitude. Although no rigorous tests of significance are available for the apparent peaks in January-February and June, they

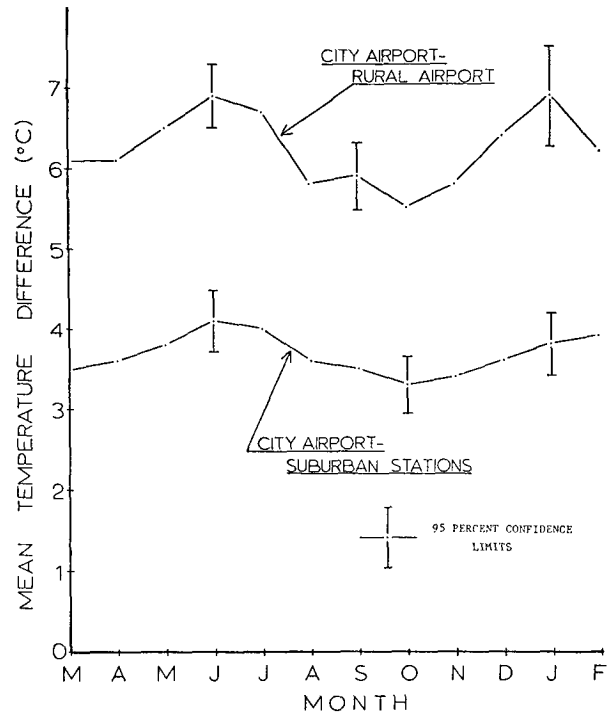


FIG. 2. Running-mean (3 month) maximum temperature differences for nights with intense heat islands in Edmonton, Alberta (2 years data).

were present in each of the two years and they were present in both mercury thermometer and bimetal data. Confidence limits derived from the Students' t test, assuming that individual heat island nights were independent of each other, are shown for selected months. The apparent peaks coincided with the months of maximum solar heating and maximum artificial heating. Whether or not this is coincidental must await tests with models that include not only the heat sources but also the heat exchange processes.

4. Diurnal cycle

Five-hour mean temperature differences for each hour of the day in winter are shown in Fig. 3. Both sets of urban-rural temperature differences showed a well-defined maximum about 3-4 hr after sunset followed by a relatively slow decline in intensity. Even at midday the urban airport temperatures exceeded those at the rural airport by $1-2\text{C}$ on the average. Similar averages for May, June and July are shown in Fig. 4. Maximum intensities occurred 3-4 hr after sunset; this was a result found to be valid for all seasons. The mean airport temperature differences were $\leq 0.2\text{C}$ between the hours of 0900 and 1600 MST.

Mean vertical temperature gradients taken from the CN Tower near the city center are shown in Fig. 5. The times of sunset and sunrise and the times of maximum heat island intensity are included in the figure for comparison purposes. Positive temperature gradients

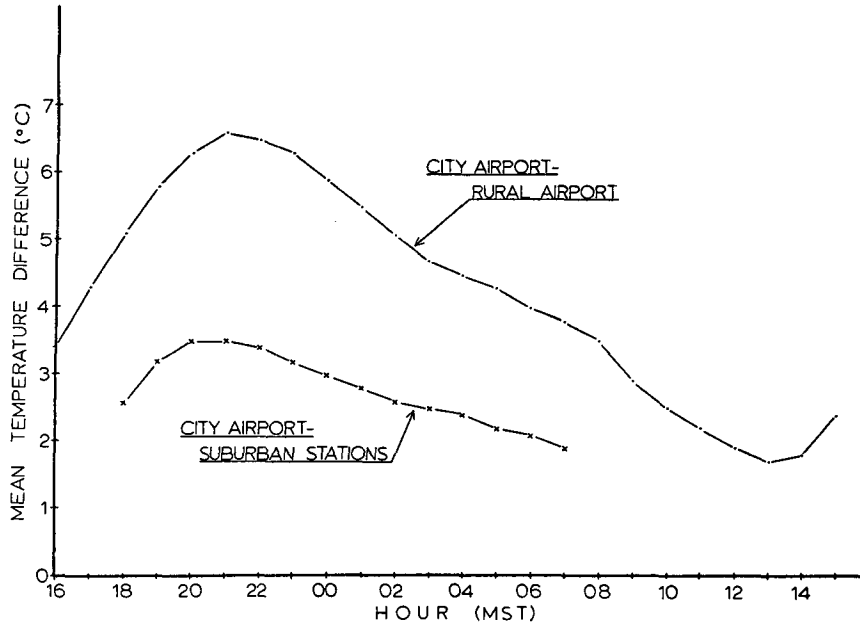


FIG. 3. Running-mean (5-hr) temperature differences for nights with intense heat islands in Edmonton, Alberta (2-year means for December, January and February).

(inversions) prevailed in the lowest 100 m over the city at all hours in the winter and from sunset to 1-2 hr after sunrise in early summer. Maximum vertical temperature gradients occurred shortly after local midnight with little month-to-month variation. The order of events was 1) maximum heat island intensity, 2) maximum vertical temperature gradient, and 3) minimum surface temperature, in all seasons. The curves shown in Figs. 3-5 suggest that the natural diurnal

heating and cooling cycle, interacting with urban and rural surfaces, played a dominant role in producing the observed diurnal heat island intensity variations. However, the winter curves (Figs. 3 and 5) suggest that artificial heating of the urban surface may have been responsible for the lack of a rapid decline in heat island intensity after midnight, and for maintaining the daytime heat island.

The maximum urban-rural temperature differences

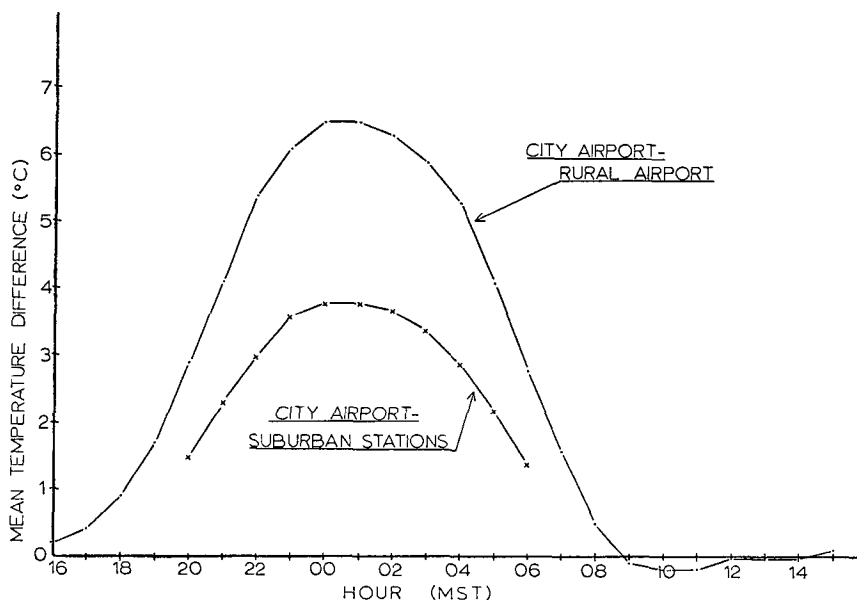


FIG. 4. Running-mean (5-hr) temperature differences for nights with intense heat islands in Edmonton, Alberta (2-year means for May, June and July).

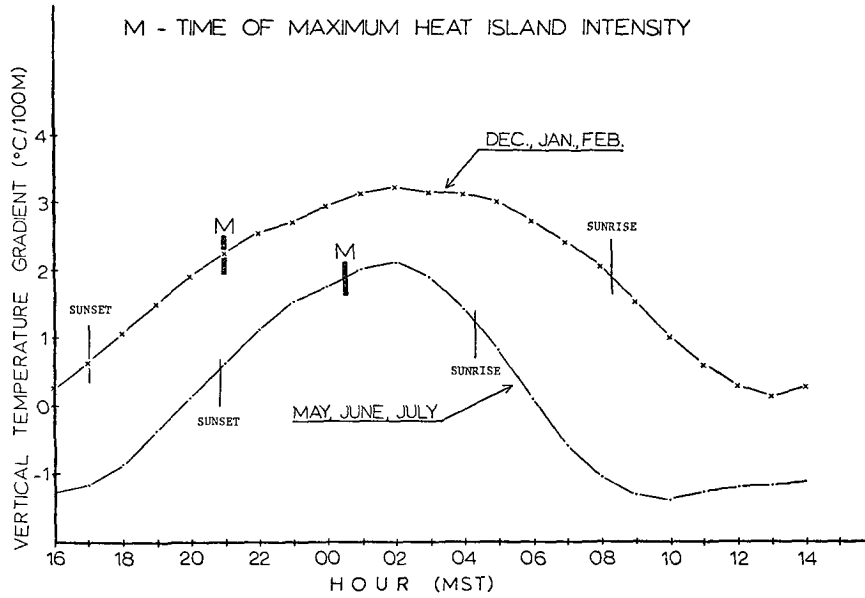


FIG. 5. Running-mean (5-hr) central urban vertical temperature gradients on nights with intense heat islands in Edmonton, Alberta (2-year means).

shown in Figs. 2-4 are large fractions of the total fall in temperature during the night. Surprisingly, however, formulas such as those of Brunt (1941), which yield

reasonable estimates of nocturnal temperature changes under clear skies, fail to predict the occurrence of a maximum temperature difference between urban and

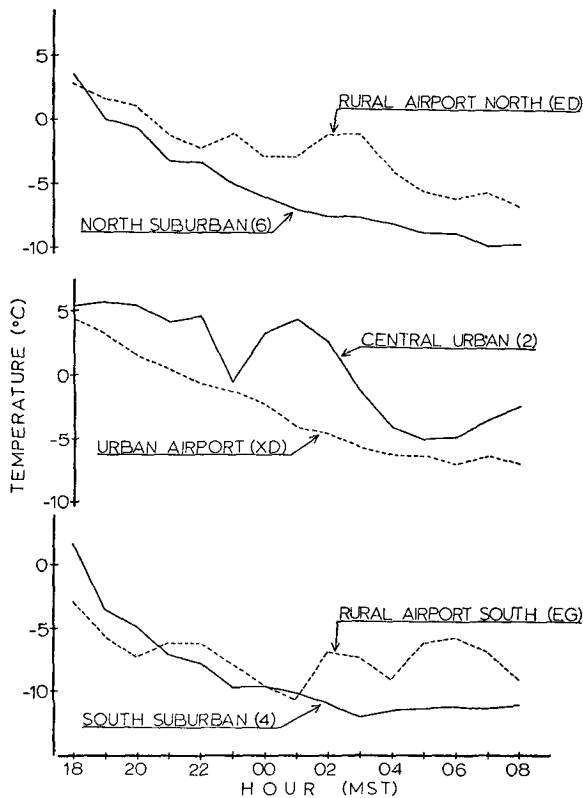


FIG. 6. North-south cross section of hourly surface temperatures on 22-23 February 1970 in Edmonton, Alberta.

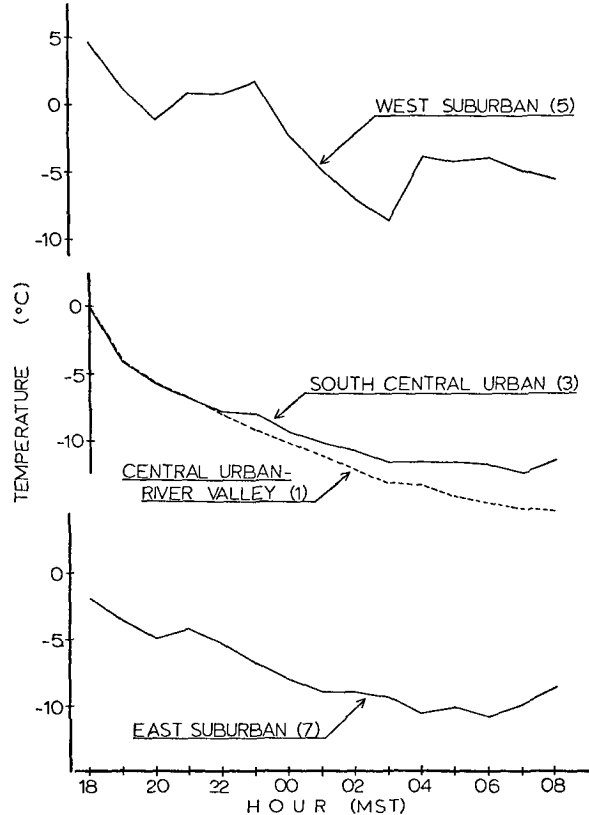


FIG. 7. East-west cross section of hourly surface temperatures on 22-23 February 1970 in Edmonton, Alberta.

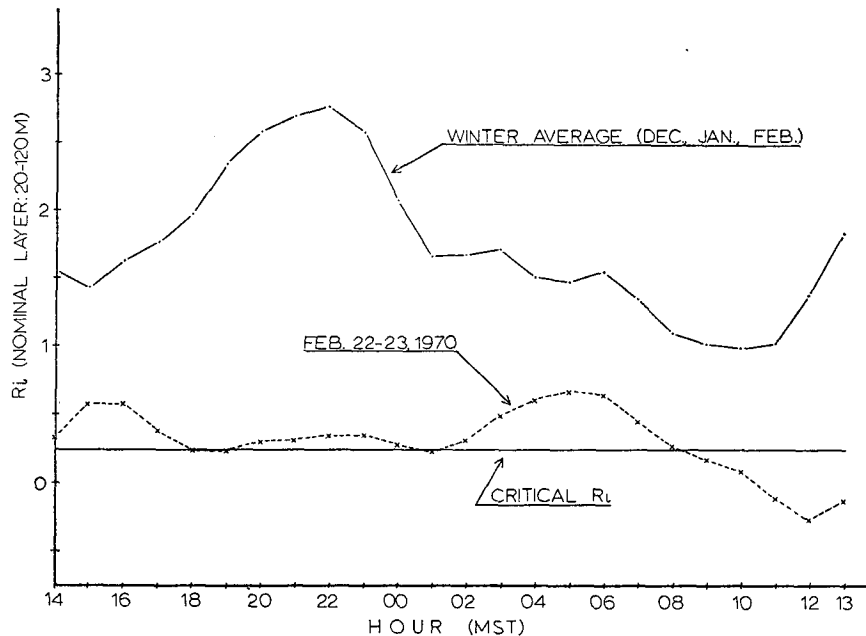


FIG. 8. Richardson numbers (R_i) based on urban temperature and wind profile data on nights with intense heat islands in Edmonton, Alberta.

rural surfaces. A somewhat more elaborate heat island model proposed by Myrup (1969) predicts maximum heat island intensities in daytime hours. It has been suggested by Gaevskaya *et al.* (1963) and others that radiative flux divergence must be included explicitly in realistic models for time changes in temperature near the surface. Inclusion of longwave radiative flux terms appears to be a logical step in the development of models to account for the gross feature of the urban heat island.

5. Inversion breakdowns

On individual intense heat island nights in fall, winter and spring occasional inversion breakdowns occurred, resulting in large variations in maximum heat island intensity. Such breakdowns, in the presence of strong vertical wind shear, are known from earlier studies (Durst, 1933; Gifford, 1952) and are not restricted to urban areas. However, the relatively dense network of surface temperature stations used in this study provides some information on the horizontal extent of inversion breakdowns. An example is shown in Figs. 6 and 7. Inversion breakdowns at individual stations were characterized by surface temperature increases of 4–6°C lasting for a few hours. Intermediate stations (1,3,4,6,7,XD) showed no evidence of comparable temperature fluctuations. Evidently at the surface, at least, the inversion breakdowns were patchy and of small horizontal scale—less than 3 km in some instances.

Very crude estimates of Richardson numbers were obtained from CN Tower vertical temperature differences and from wind speed differences based on CN

Tower (115 m) and Edmonton Industrial Airport (13 m) wind data. Winter averages (intense heat island nights) and estimates for the date shown in Figs. 6 and 7 are given in Fig. 8. On the night of 22–23 February 1970, winds $> 8 \text{ m sec}^{-1}$ were reported at 115 m and estimates of R_i varied between about 0.25 and 0.70. A critical Richardson number of 0.25 has been derived by Miles and Howard (1964) for the development of Kelvin-Helmholtz waves. Unfortunately, as pointed out by Lyons *et al.* (1964), many experimental estimates of R_i , including the ones reported here, are much too crude to identify clearly a critical value for the onset of turbulence and inversion breakdown. At best it can be said that the vertical stratifications of wind and temperature on the night of 22–23 February 1970 resembled those required by theory for the onset of unstable waves and that the large temperature fluctuations observed at the surface may have been caused by local destruction of the inversion by such waves.

6. Summary and conclusions

Average urban heat island intensities as measured by horizontal surface temperature gradients on nights favorable for strong heat islands in Edmonton, Alberta, showed remarkably steady values from month to month with some evidence of weak maxima in January and June. The intensities increased to a maximum 3–4 hr after sunset in all seasons. Vertical temperature gradients in the lowest 100 m over the central urban core reached a maximum shortly after midnight on intense heat island nights in all seasons. A stable vertical stratification persisted through all hours of the day following strong heat island nights in the city in winter.

Temporary inversion breakdowns occurred in the presence of strong vertical wind shear. Inversion breakdowns affecting the surface level appeared to be patchy and of rather small horizontal scale.

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