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Urban Climate and Air Quality of Hiroshima City (1st Report)

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1. Introduction

The effects of human activities on urban climate are many and varied. As W. H. Terjung shows it as urban process-response system, the urban climate is very complex system which models man in the setting of an urban landscape.

Studies on urban climate were reviewed by Kratzer,[1] Daigo and Nagao,[2] Oke,[3] and Kawamura,[4] Major concerns have been on the distribution of air temperature and also distribution types or their cause is explained mostly morphologicaly by the distribution pattern of air temperature. Very recently, however, some climatologists have conducted to investigate the urban climate through the heat-budget theory and regarded it as a kind of thermal pollution.

Thermal pollution and making-it-as-in-desert of urban atomosphere are caused by a various kind of factors, one of which is thought to be the declining cooling effect due to the decreasing water surface in urban area. Therefore, the purpose of this paper is to clarify how the heat balance at the surface of urban area is effected by the river water running through the city.

In the Ohta River Delta, there are flowing six rivers; the Ohta Canal, the Tenma-*kama*, the Hon-*kawa*, the Motoyasu-*kawa*, the Kyohbashi-*kawa*, and the Enkoh-*kawa*. The fact that the wealthy water of the Ohta River plays an important role in lightening the thermal pollution of city atomosphere has been discussed qualitatively (Shitara[5]). In this study, we put emphasis which features of heat budget can be considered most effective.

2. An outline of climate in Hiroshima City

It is not so difficult to measure the part that weather has played in the growth of city. According to the climatic classification by Köppen, Hiroshima shows C-type, that is, mild climate as Los Angeles (USA) and Hsü-chou (China) at the same latitude with Hiroshima do. But their climates are quite different with each other especially on the patterns of annual variations of air temperature and precipitation which are shown by hythergraphes (See Fig. 1).

Hiroshima's weather is truly variable in its character just as Japanese climate is. As the year passes, one can experience various types of weathers such as hot summer days with calmness (*nagi*), slightly cold winter days with chilly Ohta-river wind, etc. The highest temperature, lowest humidity and plentiful sunshine produce droughts sometimes during summer. Tyhoons sometimes retain much energy and moisture as they move northward or eastward, usually they pass out of Hiroshima.

As shown in Fig. 1, Hiroshima's climate is hotter in summer and colder in winter

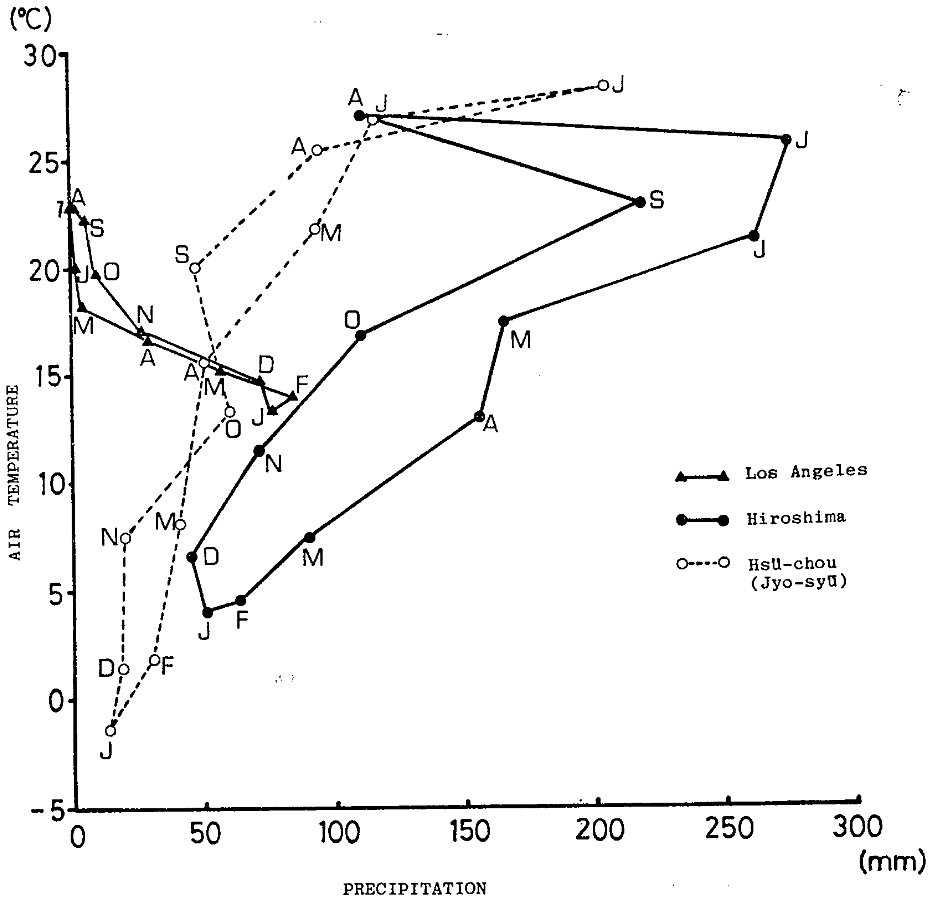

Fig. 1 Hythergraph.

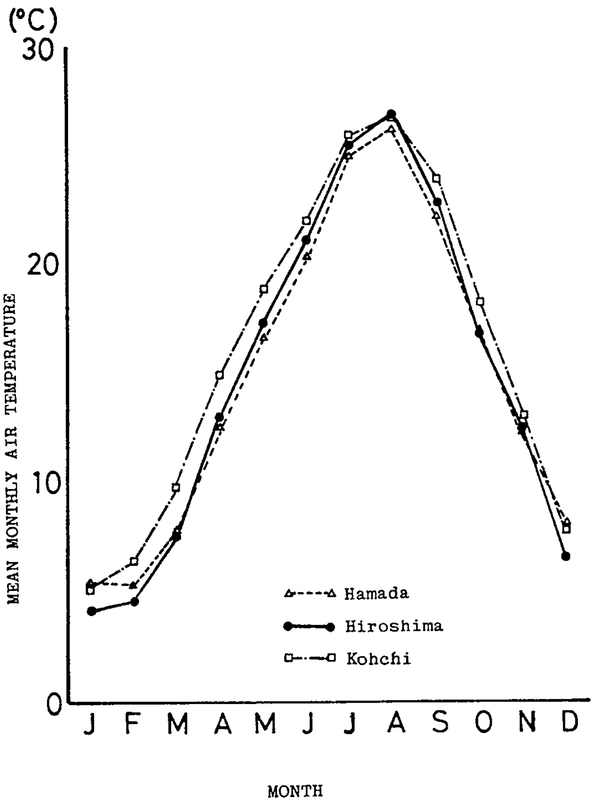

Fig. 2 Annual Variation of Air Temperature

than Los Angeles' one. On the other hand, some geographers say that Seto-uchi (the Inland Sea) makes the climate more moderate, i.e. cooler in summer and warmer in winter in comparison with other regions in Japan. Such a climatological expression, however, is not exact because Hiroshima's winter is rather colder than Kohchi's (Pacific Ocean side) and Hamada's (Japan Sea side) ones while summer in Hiroshima is almost the same with Kohchi and hotter than in Hamada (See Fig. 2).

Concerning about wind, the regular alternation of land- and sea-breezes is recognized even in average annual stream lines drawn by using wind-roses at nine stations[6] (See Fig. 3). The stream line at 9 o'clock A.M. indicates land-breeze with a sea-breeze front in the southern extremity of the Hiroshima Delta. The sea-breeze is obviously found in the stream line at 3 o'clock P.M. It will be later discussed that such land- and sea-breezes do not have so distinct influence on the heat-island except riversides around where "*Kawa-kaze*" river-wind (breeze) is also prevailing.

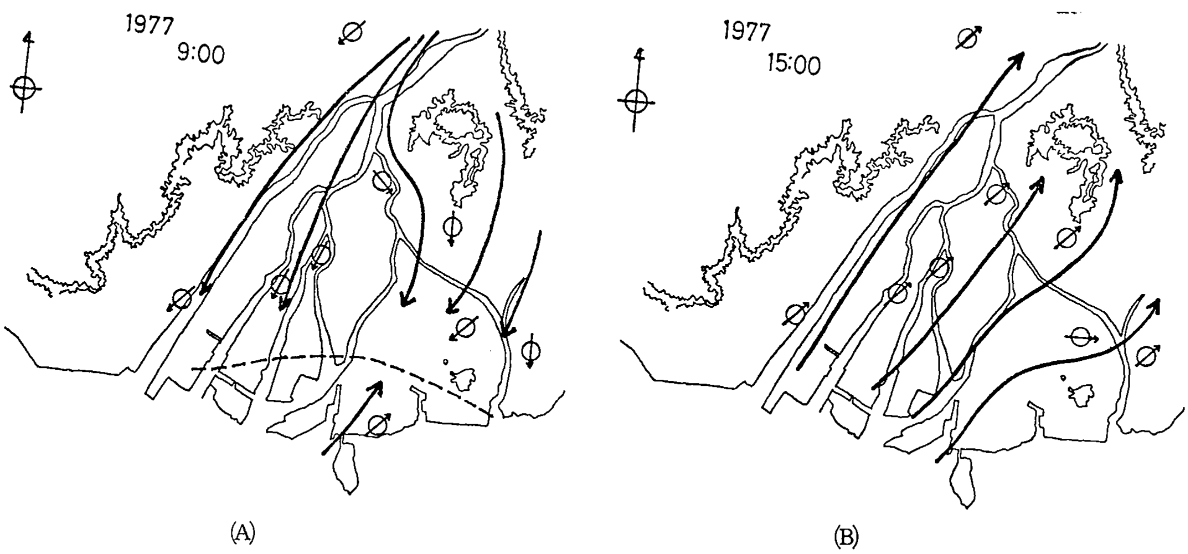

Fig. 3 Stream Line (annual mean)
(A) at 9:00 (Broken line shows Sea-breeze Front.)
(B) at 15:00

3. Urban climate of Hiroshima City

3-1 Study area and the method

From the purpose of this study to make clear how the heat-budget at the urban surface is influenced by the river water, it is unnecessary to compare the inner district of the urban area with the suburban area. In this study, we kept the accent on observing the water temperature of five tributaries of the Ohta River and the air temperatures (dry-and wet-bulb) at two heights of 30 and 180 cm above the road and the bridge. At the same time, the insolation, net radiation, wind velocity and surface temperature were measured to get the horizontal distribution of some items of heat economy. While the surface temperature and the wind velocity were sounded by the infrared thermometer (National Co.) and the anemometer (Kanomax Co.) respectively, the other meteorological elements were obtained by a set of integrated meteorological measuring apparatus (Iio Co.) mounted on the car.

The moving observations were carried on April 22nd to 23rd, May 12th to 13th, July 17th to 18th, August 9th to 10th, October 21st to 22nd, November 3rd to 4th and December 17th to 18th. And besides, we moved around the built-up area three times a day. In order to adjust the time-variation, we adopted the cross-check method.

3-2 Results and Discussion

(1) Distribution of Air Temperature

In this papers, we discuss about three cases of April 22nd (daytime), August 9th (nighttime) and August 10th (early morning). The former example is typical as a heat-island influenced by the river water and the latter two examples show the variation of the heat-island pattern. As shown in Fig. 4, it is obvious that the air temperature above river water surface is lower by 4°C than the central part of heat-island.

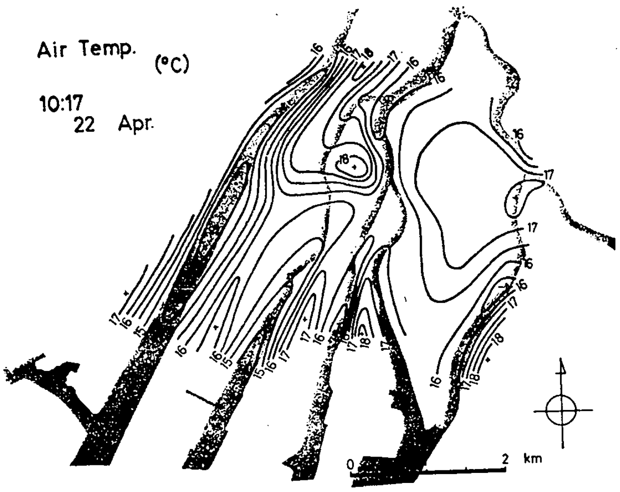

Fig. 4 Distribution of Air Temperature, at 10:17 (Apr. 22, 1978)

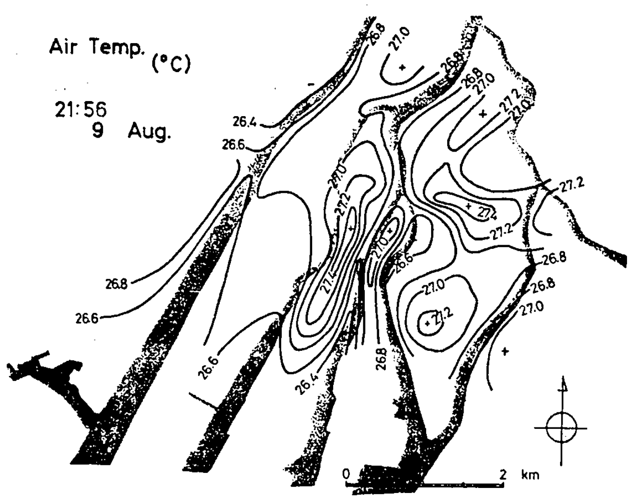

Fig. 5 Distribution of Air Temperature, at 21:56 (Aug. 9, 1978)

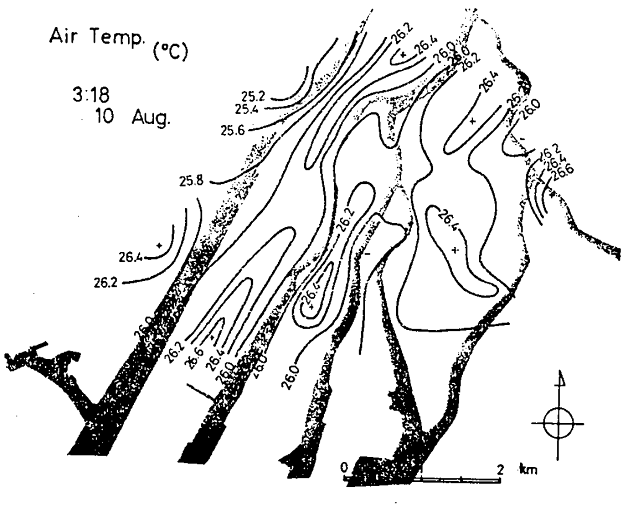

Fig. 6 Distribution of Air Temperature, at 3:18 (Aug. 10, 1978)

Compared Fig. 5 with Fig. 6, it is recognized that the pattern of temperature distribution varies as time passes.

Generally speaking, the intensity of heat-island, i.e., the temperature difference between urban center and suburbs becomes the largest in the early morning. But the temperature difference of the surface river-water and the heat-island presents the inclination to decrease from night to early morning.

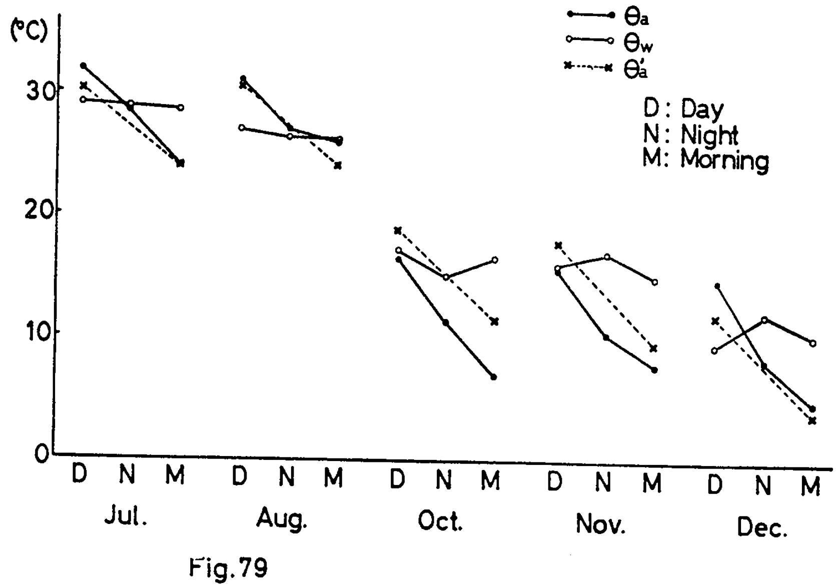

Fig.7 Mean Air Temperature of Built-up Area(θa), Mean Water Temperatue(θw) and Nomal Air Temperature Hiroshima Weather Station(θa').

The study by Shitara[5)] was done without measuring river-water temperature simultaneously. In our study, we sounded the surface water tempcrature by infrared thermometer just like a remote sensing method and to consider it with relation to air temperature from the view-point of heat-balance. Fig.7 indicates the average air and water surface temperatures (Θa & Θw) at 18 bridges and the mean 30-years' temperatures of daily maximum and minimum (Θa') at Hiroshima Meteorological Observatory about the same days on a calendar. In comparison Θa with Θa', the observation days in October and November were thought to be rather colder for this season. It can be said that the seasonal variation of the water temperature is proportional to that of the air temperature.

As for the daily change, the water temperature does not always present so simple or periodic variation as the air temperature does, i. e., the maximum at midday and minimum at early morning. This is explained by Fig.8 which shows the daily fluctuation of the tidal level and the water-temperature observed using a rubber boat on the Ohta Canal. It is ascertained that the water temperature gives two peaks a day independently of the air temperature, and that it changes in good correspondence with the variation of tidal height. This means that during the summer the water temperature goes down at high tide when the sea water flows into because the river water is warmer than the sea water with the larger heat capacity. (Near the mouth of the Ohta River, the height of tide varies greatly to reach usually 2.5 to 3.0m of tidal range, and even at the observation station of water temperature about 5 km upstream the range is almost 2.0m.)

Fig.7 and the distribution of air temperature (Fig. 6) give us some hint about the effect of the river water on the urban temperature. In spite of the fact that from mi-

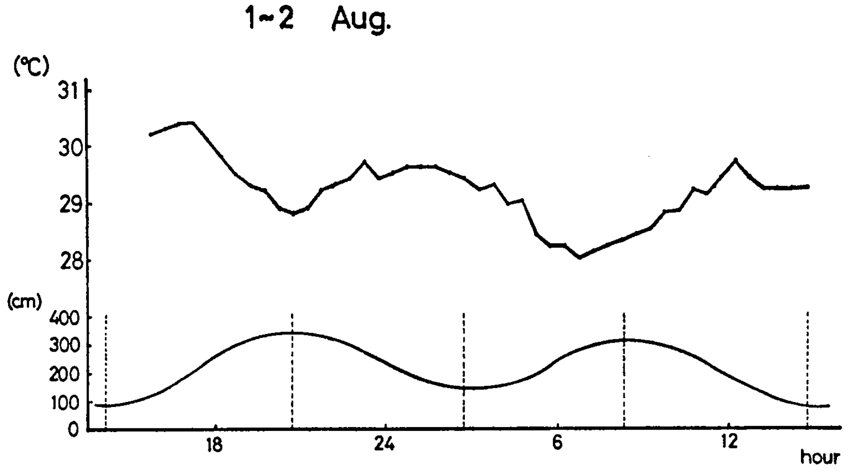

Fig. 8 Daily Variationa of Water Temperature(℃)and Tidal Height(cm).

dnight to early morning the water has higher temperature than the air every month as shown in Fig. 7, the distribution of air temperature, especially at early morning, tells that air temperature above river is lower than the built-up area. This is inconsistent with Kikuchi's[7] study in which he says that the river water plays a role as a heating source in winter. This contradiction is probably due to the environmental difference of the rivers running through; rural district in Kikuchi's case and urban district in our case. Briefly speaking, the built-up area around the river displays an effect as a warmer heat source than river water in cold season.

(2) Distributions of sensible heat ($\Delta\Theta$) and latent heat ($\triangle E$)[8]

The heat flux conducted from the heated urban surface (asphalted roads, concrete buildings, etc.) and convected in the atmosphere is called "sensible heat" while the heat transfer by evapotranspiration (from rivers, parks, fields, etc.) is called "latent heat". For instance they are expressed by the bulk-aerodynamic method as follows.

Sensible heat flux ; $H=\rho CpDh(Ts-T)$ ……………(1)

Latent heat flux ; $LE=0.622\cdot L\rho\frac{Dw}{P}(e_s-e)$ ……………(2)

where ρ, Cp, Dh, L, Dw, P, Ts, T, e_s, e are, respectively, the air density, the specific heat of air at constant pressure, the molecular diffusion coefficient for heat, the latent heat of evaporation, the molecular diffusivity for water vapour, air pressure, surface temperature, air temperature at a given height, vapour pressure at surface and vapour pressure at a given height.

In this study, we were not able to determine H and LE themselves because it is quite difficult to get Dh and Dw. Therefore, supposing that ρCpDh in the equation (1) and $\rho\frac{Dw}{P}$ in (2) are constant and that Ts-T and e_s-e are proportional to $\Theta_{30}-\Theta_{180}=\Delta\Theta$ and $e_{30}-e_{180}=\Delta E$ respectively, we took a bird's-eye view of the distributions of sensible and latent heat by using those of $\Delta\Theta$ and ΔE.

Against expectation, ΔE distribution does not find the effect of river water on $\Delta\Theta$ so

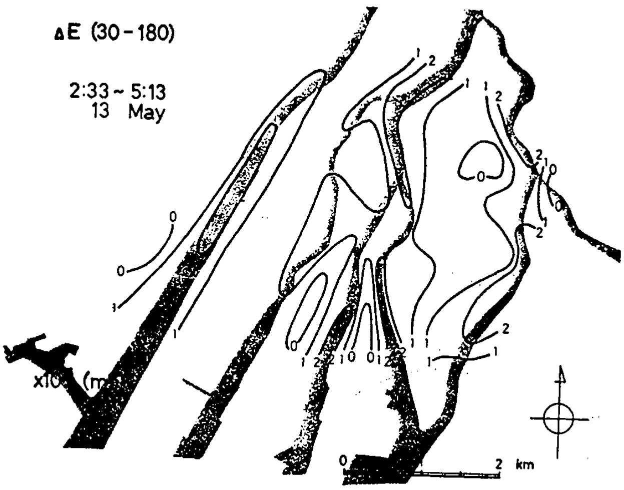

Fig. 9 Distribution of △E(Vapour pressure Gradient)

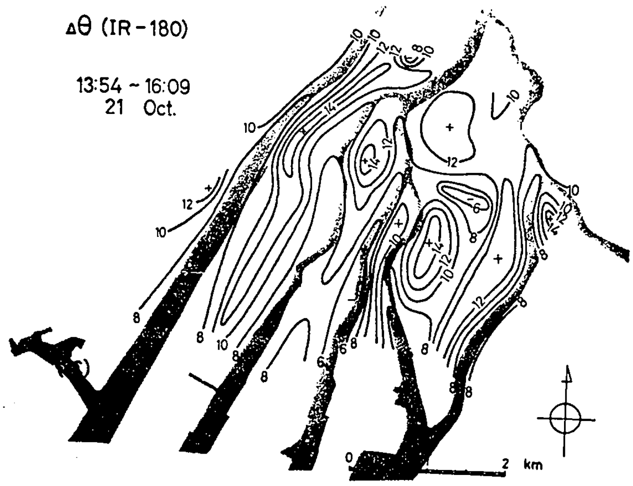

Fig. 10 Distribution of △θ (Temperature Gradient at Midday Oct. 21)

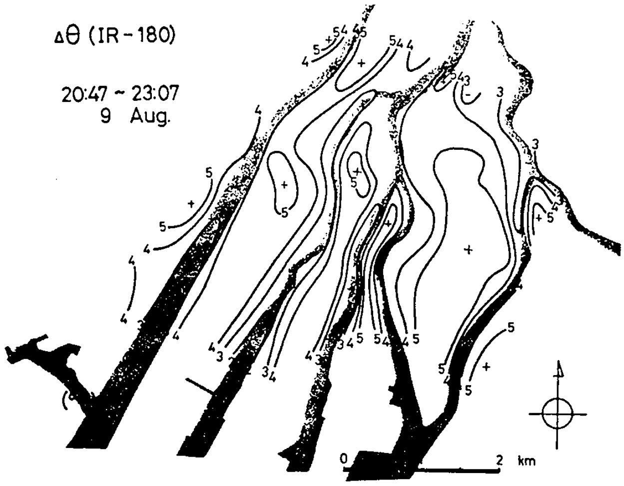

Fig. 11 Distribution of △θ (Temperature Gradient at Midnight Aug. 9)

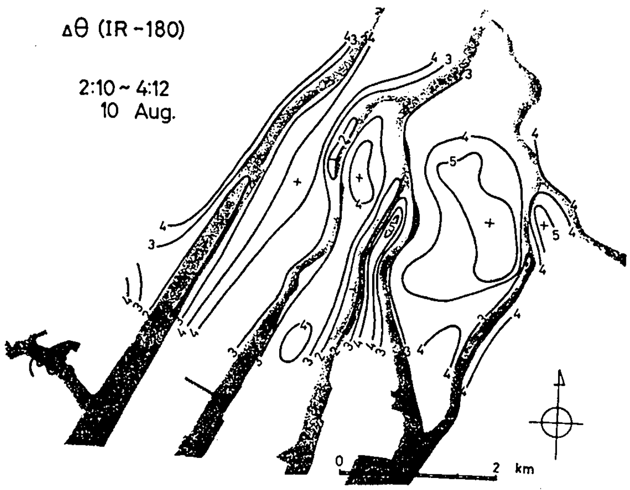

Fig. 12 Distribution of △θ (Temperature Gradient at Early Morning Aug. 10)

distinctly. But ΔE above the river has a tendency to be slightly larger than the other districts. It means that the evaporation is more active from the river in comparison with other surfaces. Fig. 9 shows the distribution of ΔE in the early morning of May.

It is more difficult to find the effect of the river water on the ΔΘ distribution. So, we drew the isoline of the temperature gradient ΔΘ using Θir (surface temperature observed by infrared thermometer) instead of Θ_{30}. Results are manifested in Figs. 10, 11 and 12, where Θir above the river is not the surface water temperature but the surface road temperature. It may be recognized that ΔΘ around rivers is smaller than one in the built-up area. In addition to the rivers, the area of small temperature gradient comes out in daytime distribution (See Fig. 10). This corresponds to "cool-island" born in the district with high buildings. Figs. 11 and 12 are, respectively, the midnight and early morning distributions. Their patterns are rather simple in comparison with the daytime condition as shown in Fig. 10, and besides the pattern does not change so largely from midnight to early morning.

4. Conclusion

When we compare our result with Shitara's one (Fig. 13), it may be concluded that the difference of air temperature between the central part of heat-island and the river has increased for almost a quarter century.

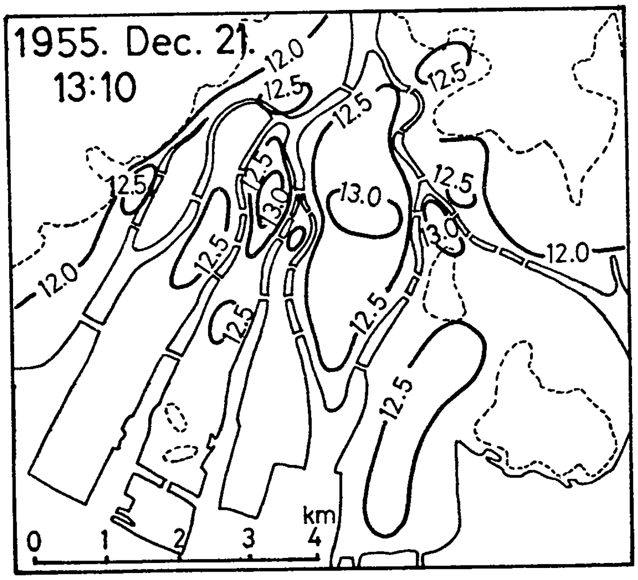

Fig. 13 Distribution of Air Temperature (Shitara, 1957)

From the view point of heat balance, the river water has an effect on moderating urban temperature, not because the coldness of the water but because of cooling action of the latent heat flux by the evaporation.

The value $\Delta\Theta$ using Θir (infrared thermometer) suggests the mild sensible heat flux on the bridges, which can not be explained only by the heat budget of Z-direction (vertical flux). Terefore, we have to consider the effect of the cool air advection on lowering the surface temperature of the bridges.

Acknowledgement

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広島市の都市気候と大気汚染（第１報）

〔要　約〕

本研究は，広島市の都市気候と大気汚染に関する気候学的研究であるが，第１報では主として前者について論じた。①まず，広島市の気候についての概観では，典型的な大陸東岸気候の中にあって，「夏は太平洋地域より涼しく，冬は日本海側より暖かい」という従来の説が妥当でないことを指摘し，かつ年平均流線図の上にも海風前線の存在が確認された。②次に，都市気温分布とそれに及ぼす太田川水系の影響に関しては，約４半世紀前にくらべ，built-up area と川面との気温差が増大していることが自動車による移動観測の結果わかった。③この川水の影響は，水温そのものの冷源（または熱源）効果よりも，水面からの蒸発に伴なう潜熱交換が気温緩和作用をもたらしているからと考えられる。④赤外放射温度針での表面温度測定による顕熱輸送は橋上で小さい。すなわち，川水面上で気温が和らかげられるのは，鉛直方向の熱収支だけでなく，川面での冷気の移流も想定される。

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