Hisada, Yukiko; Matsunaga, Nobuhiro

Sea Breeze Effects on Heat Island Structure in Fukuoka Facing the Sea of Japan

SEA BREEZE EFFECTS ON HEAT ISLAND STRUCTURE IN FUKUOKA FACING THE SEA OF JAPAN

Yukiko Hisada[1] and Nobuhiro Matsunaga[2]

[1] Research Fellow RPD of JSPS, Research Institute for Applied Mechanics, Kyushu University
Kasuga, Fukuoka, 816-8580, Japan, e-mail: yukistar@esst.kyushu-u.ac.jp
[2] Professor, Department of Earth System Science and Technology,
Interdisciplinary Graduate School of Engineering Science, Kyushu University
Kasuga, Fukuoka, 816-8580, Japan, e-mail: matunaga@esst.kyushu-u.ac.jp

ABSTRACT

We have made simultaneous observations of temperature at 71 points in Fukuoka metropolitan area since the summer of 2003. We sampled 62 days as days of particular sea-breeze occurrence based on wind data obtained from the Fukuoka District Meteorological Observatory. The data show that high temperatures were moderated by the sea breeze. The temperature fell rapidly after the sea breeze reached the area. This effect is apparent in an area of 20 km inner from the coast.

Keywords: heat island, see breeze, cooling effect

1. INTRODUCTION

Urban heating is a serious environmental problem confronting many large cities. The Fukuoka metropolitan area, with a population of about 1.77 million, is the largest of Kyushu Island, Japan. It is situated on the north side of Kyushu and faces the Sea of Japan. Its annual mean temperature rose 2.5°C during the century from 1901 to 2000. Furthermore, the annual mean values of daily mean temperature in the summer have increased by 0.39°C / 10 years from 1985 to the present[1)]. Urban heating in the Fukuoka metropolitan area is progressing remarkably. Therefore, long-term observations covering the entire Fukuoka metropolitan area are necessary to elucidate the present conditions of urban heating. On the other hand, the effects of sea breezes were first noticed as measures to moderate urban heating. A strong and stable sea breeze is often generated in the Fukuoka metropolitan area[2)]. Its winds originate in the north or northwest and the intrusion time of the sea breeze is between 0700 JST and 1300 JST. However, its cooling effects have not been clarified yet. It might be useful to investigate its effect on heat island structure to maintain comfort in thermal environments in large cities.

We have measured temperatures throughout the Fukuoka metropolitan area since the summer of 2003. In this study, we analyzed the effects of sea breezes on heat island structure using those temperature data and wind data obtained at the Fukuoka District Meteorological Observatory (FDMO) and meteorological observatories of the Fukuoka Urban Expressway. Sixty-two days in the summer seasons of 2003 and 2004 were sampled as days when the sea breeze occurred noticeably. The probability of sea-breeze occurrence was 41%[3)]. Generally speaking, the frequency of their occurrence is very high among large coastal cities.

2. OBSERVATION METHODS

Figure 1 shows the topography and measurement sites of the Fukuoka metropolitan

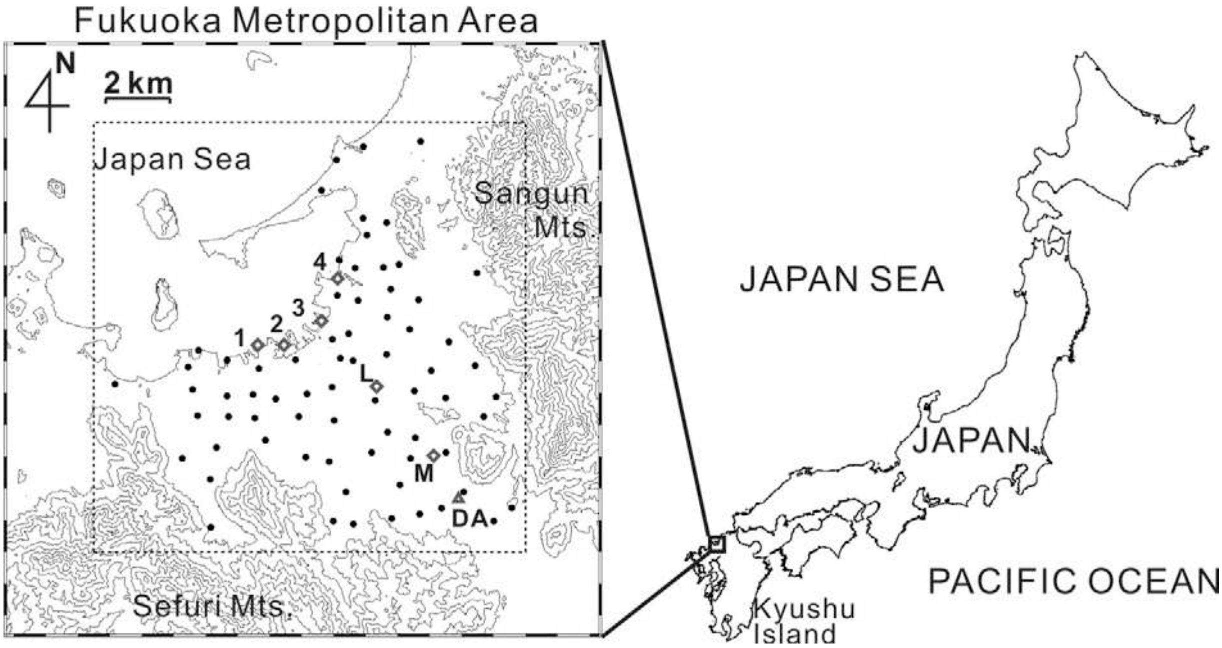

Fig. 1 Topography of Fukuoka metropolitan area and the measurement sites.
close circles : the sites of thermometers and thermo-hygrometers
open triangle : AMeDAS in Dazaifu
open diamonds : meteorological observatories of Fukuoka Urban Expressway

area. The Sea of Japan lies to the north of Fukuoka. Mountains of about 1000 m lie on the east side and the southwest side, nearly surrounding the Fukuoka metropolitan area. Therefore, the sea breeze blows inland while converging, thereby gaining strength and stability. Figure 1 shows sites of thermometers and thermo-hygrometers as closed circles. The open diamonds points 1-4, L and M show sites of meteorological observatories of the Fukuoka Urban Expressway. Point 3, L and M are respectively located 0 km, 9 km and 19 km inland. Wind data obtained at these sites were used. The open triangle shows the Dazaifu AMeDAS (DA) site. It is situated 23 km inland. Wind data and temperature data obtained at DA are used. We set 32 thermo-hygrometers and 39 thermometers in 70 instrument shelters of elementary schools and in a shelter of Research Institute of Kyushu University Forest. Thermo-hygrometers of SK-L200TH and thermometers of SK-L200T and Jr.TR-52 were used. The maximum error among them was less than 0.2°C. The observation sites were selected to provide one for every 4 km^2. The maximum value of the altitude differences among the observation sites was about 40 m. Therefore, their temperature difference is estimated as less than 0.24°C. In these data analyses, no temperature correction was made for the error among thermometers and the altitude differences because they were regarded as sufficiently small in comparison with the cooling effect by the sea breeze. The data acquisition interval was 5 min. In all, 62 days were chosen as sea-breeze occurrence days during 18 July 2003 – 13 September 2003 and 14 June 2004 – 14 September 2004.

3. RESULTS AND DISCUSSION

3.1 Variation of air temperature distribution in the Fukuoka metropolitan area

Figure 2 shows the time variation of spatial distributions of temperature 0930, 1030, 1130, 1230, 1330, and 1430 JST on August 2, 2003. The intervals of solid and broken isotherms respectively show 1°C and 0.2°C. No sea breeze invasion was detected at any

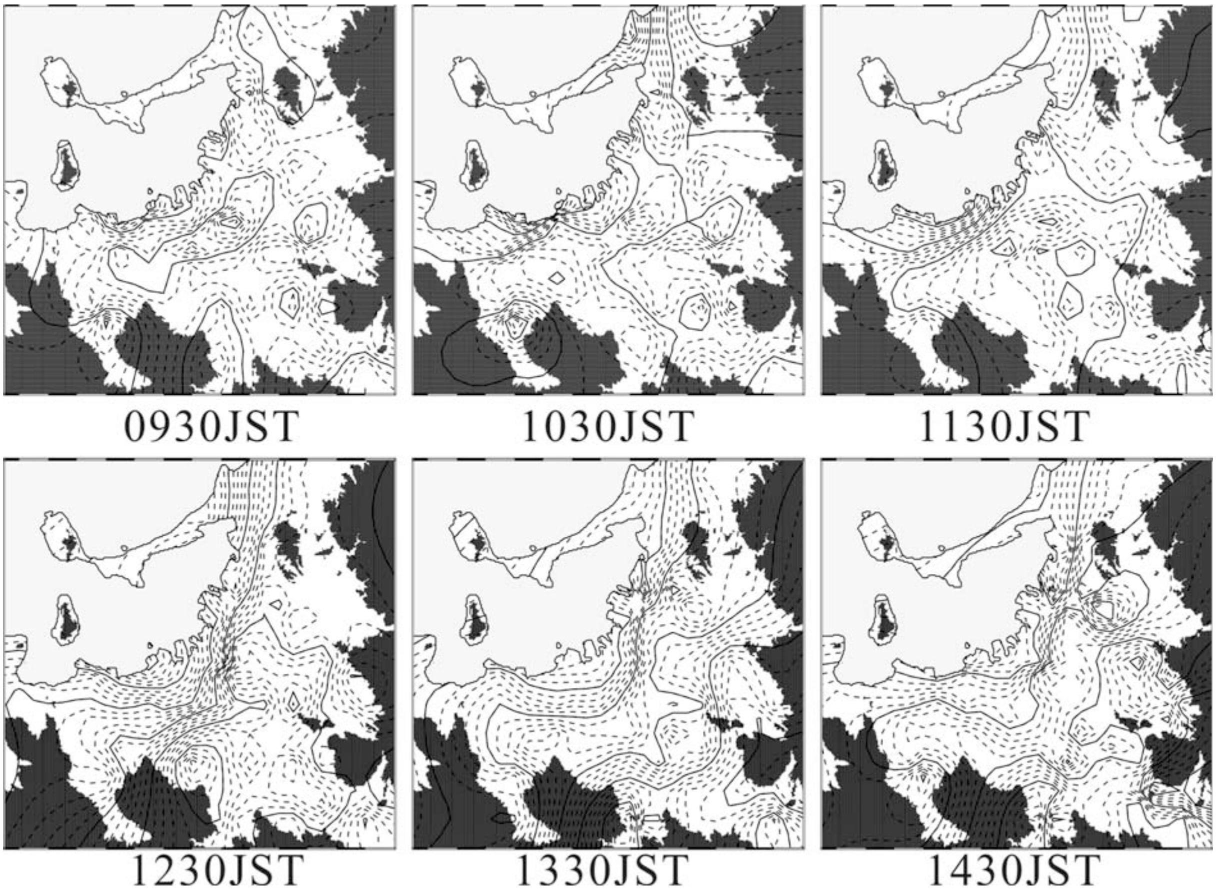

Fig. 2 Time variation of spatial distributions of temperature on 2 August 2003.

observation point at 0930 JST. The air temperatures of the coastal and inland region are similar at that time. A 31°C isotherm spans the metropolitan center, which has a uniform air temperature distribution. Sea breeze invasion was observed only at Point 1 at 1030 JST. An isotherm parallel to the coastline was identified in the west, suggesting an air temperature difference between the coastal and inland regions. Sea breeze invasion was observed only at Point 1 at 1130 JST, as with 1030 JST. The warming of air in western Fukuoka is more suppressed than in central Fukuoka. The air temperatures of the inland and coastal regions differ greatly, with a much higher air temperature in the metropolitan center. Sea breeze invasion is observed at 1230 JST at Points 1–4. No warming is evident on the coast, although isotherms with a small gap parallel to the coastline reach the metropolitan center, which sharply differs from 1130 JST. The air temperature difference between inland and coastal regions is greatest at this time. Sea breeze arrival occurs at 1330 JST at Points L and M. The isotherm interval spreads and the inland region air cools rapidly, but the air in the southeast remains warm. Despite the lack of cooling at the coast, the warming of air is suppressed. A sea breeze arrived at 1430 JST at Point DA. By this time, the relaxation effect of sea breeze had reached the inland region. The Fukuoka metropolitan area air is 31–33°C in a large range, except for the coast and the mountain foot in the southeastern part. Such an air temperature distribution is apparent for other real sea breeze occurrences, although no data are presented here. The coastal sea breeze relaxation effect is sufficient to affect the inland region. Coastal air is cool, but the southeastern air is warm because of the sea breeze effect. Low temperatures along the shore occur when marine atmospheric air is conveyed over land by a sea breeze, thereby suppressing air warming. Warming in the southeast might be attributable to heat advection from the metropolitan center by sea breezes.

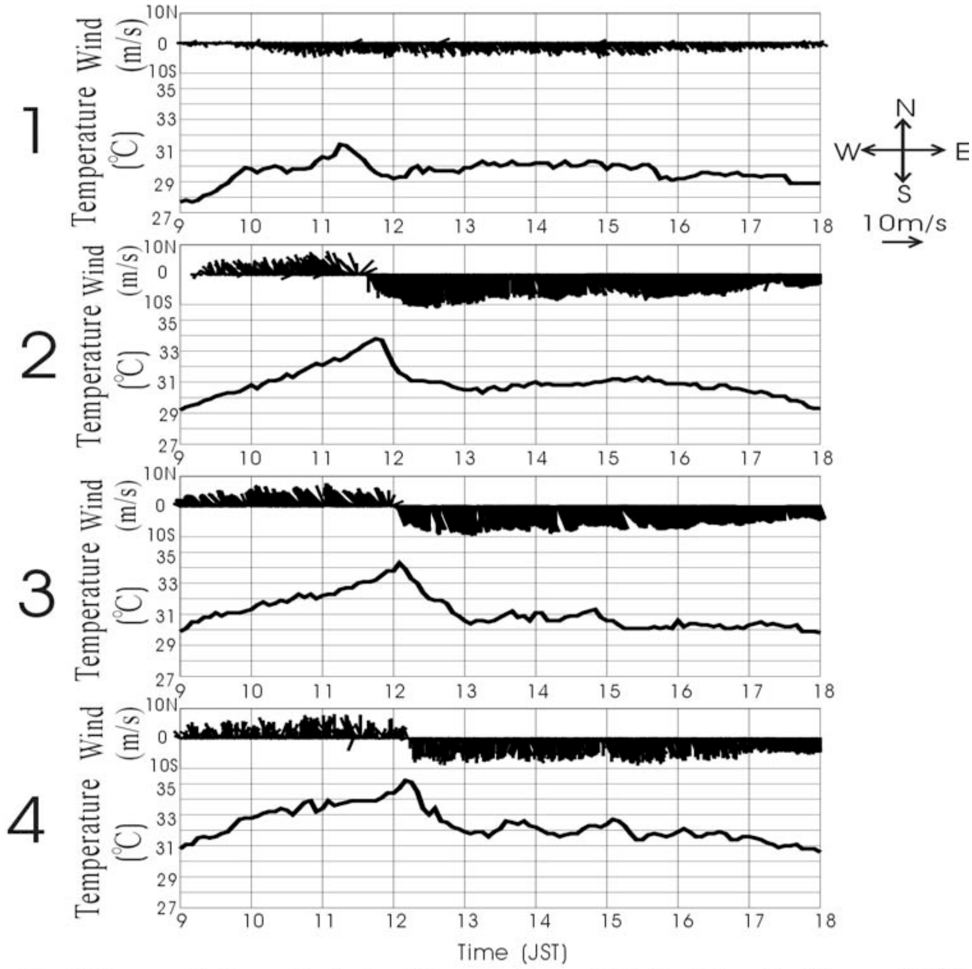

Fig.2 Time variations of wind and temperature at 1,2,3and 4 on 2nd August 2003

3.2 Effect of sea breeze on the coast

To study the invasion situation of sea breeze and relaxation effect thereof, the variation of wind direction, wind speed, and air temperature at observation points on the coast were observed. Their relationship was investigated. Figure 2 shows time variations of wind direction, wind speed, and air temperature during 0900–1800 JST, on August 2, 2003 at Points 1–4 as an actual sea breeze occurrence. The upper plot in the graph for each point expresses the wind vector at an interval of 1 min, and a line facing up denotes a southerly wind. The lower plot portrays the air temperature variation. Those data were observed at the elementary school located closest to each wind observation point. The horizontal axes of both plots denote time (JST). Sea breezes on the Fukuoka plain are mostly northerly to northwesterly, while land breezes are mainly southerly to southeasterly. Accordingly, the time at which the wind direction changes clearly from southerly to northerly is considered to be the sea breeze invasion time. At Point 1, a sea breeze started invasion at 0950 JST when the wind vector changed from southerly to northerly. Air warmed to 30°C before the sea breeze invasion, but that warming was suppressed by cool air invasion. Air temperatures changed within about 0.2°C range for 60 min after invasion. Then the wind direction fluctuated and air began to warm, cooling again after 1115 JST when the wind direction was fixed to northeasterly. At Point 2, a sea breeze invasion started at 1140 JST when the wind vector changed from southerly to northerly. The air warmed at an almost constant rate of 1.5°C/h until 1140 JST, when the sea breeze invaded. The air then cooled rapidly after sea breeze invasion, 2.9°C in 30 min; the decrease then became gentle. The maximum air temperature drop was 3.5°C. No subsequent warming occurred; the air remained at about 31°C. The air cooled concomitantly

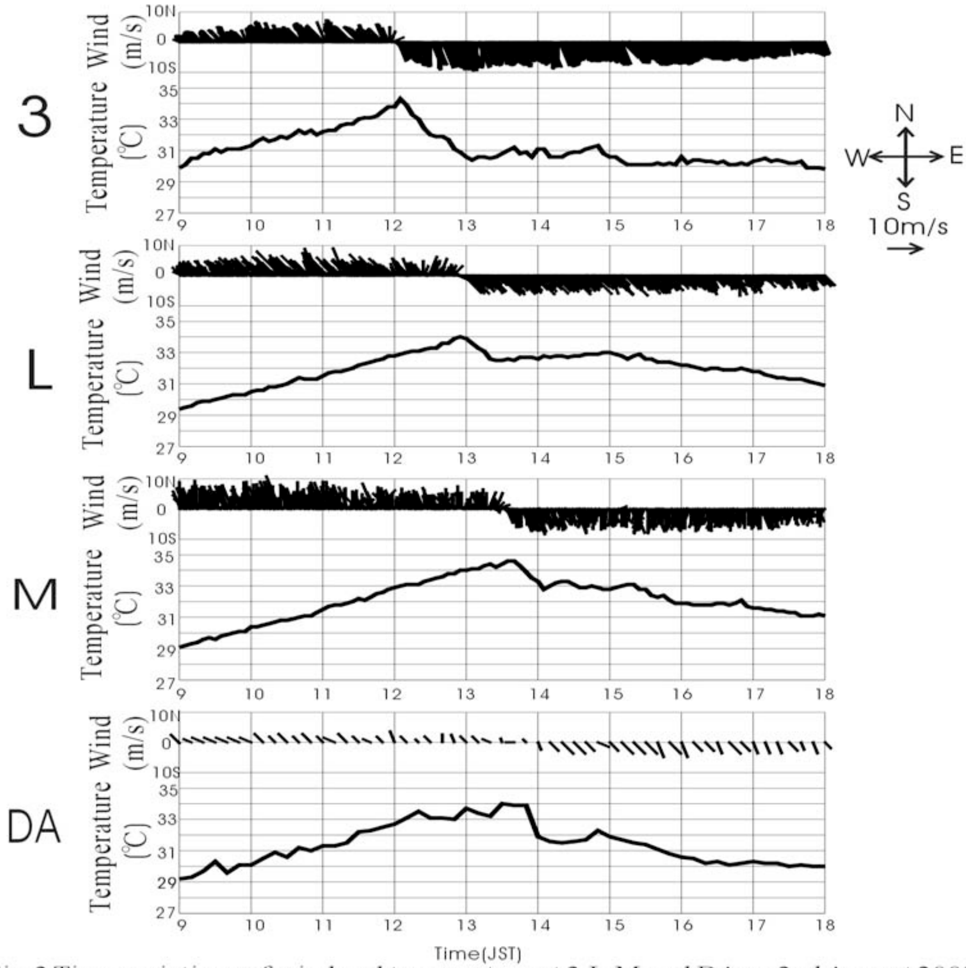

Fig.3 Time variations of wind and temperature at 3,L,M,and DA on 2nd August 2003

with time after 1600 JST. At Point 3, the wind direction change suggests the sea breeze invasion time as 1200 JST. Although the air warms until sea breeze invasion, it then begins to cool. The air continues cooling for about 60 min, during which time the maximum air temperature drop is 3.9°C. The warming is suppressed and the air remains within a narrow temperature range: *ca*. 30°C after 1520 JST. At Point 4, the wind direction change suggests the sea breeze invasion time as 1215 JST. The air warms continuously until sea breeze invasion, but it begins to cool thereafter. The cooling slows within about 60 min, as at Point 3, and the maximum air temperature drop is 3.2°C. No subsequent warming is observed. The air cools by 2–4°C within about 60 min after sea breeze invasion on the coast. The warming of the air, which is suppressed during invasion, also varies with the sea breeze's changed wind speed or wind direction. The relationship between observation point location and sea breeze invasion time reveals that a sea breeze is observed earliest at westernmost Point 1, and gradually later at points eastward. This phenomenon is often observed at real sea breeze occurrences. It is therefore verified that the sea breeze first invades the eastern part of the Fukuoka metropolitan area. Differences in sea breeze invasion time at observation points are 110, 20, and 15 min between Points 1–2, 2–3, and 3–4, respectively, on August 2, 2003, which is used as an example in this study. The differences are 20, 5, and 10 min on August 4, 2003, for example, although no data are presented. Consequently, sea breeze invasion times at each point differ greatly day by day, probably because the sea breeze arrival times differ according to the relationship between surrounding geography and structures and the sea breeze invasion direction. Alternatively, a heat source in the western Fukuoka metropolitan area might attract sea breezes early. These are future research themes.

3.3 Effect of sea breeze from cost toward inland

Figures 3 shows time variations of winds at Points 3, L, M and DA. It also shows temperatures from 1000 JST to 1800 JST on 2 August 2003. The wind direction at point 3 changes at 1200 JST, indicating that the sea breeze arrived at point 3 at 1200 JST. The temperature at K increases until 1200 JST; it subsequently decreases rapidly after the change of wind direction at point 3. The temperature decrease is almost 4°C and the temperature is almost constant after that. The wind direction at point L changes at 1250 JST. The temperature at point L decreases immediately after that. The temperature decrease is about 1.5°C. The wind direction at point M changes at 1330 JST. The temperature at point M falls after that. The temperature decrease is about 2°C. At DA, the wind direction changes at 1400 JST. The temperature at DA decreases simultaneously. The temperature decrease is about 2.5°C. The arrival of the sea breeze decreases the temperature rapidly in the Fukuoka metropolitan area.

4. CONCLUSIONS

We investigated the cooling effect of the sea breeze on the heat island structure in the Fukuoka metropolitan area. The results are as follows. The temperature increase is moderated by the sea breeze intrusion. The temperature falls rapidly after the sea breeze reaches the area. This effect is apparent in an area of 20 km inland from the coast.

REFERENCES

Hisada, Y., Ikemoto, K., Yumimoto, K. and Matsunaga, N. (2002), Climate Change at Fukuoka Metropolitan Area by Urbanization, *Japan Society of Civil Engineering West Regional Branch*.

Fukuda, K., Matsunaga, N. and Sakai, S. (2001), Behaviors of Sea Breeze above Fukuoka City, *Annual Journal of Hydraulic Engineering*, 44, pp.85-90.

Hisada, Y., Matsunaga, N. and Ando, S. (2006), The Effect of Sea Breeze on Thermal Environments in Fukuoka Metropolitan Area, *Annual Journal of Hydraulic Engineering*, 50, pp.487-492.