INFLUENCE OF THE URBAN HEAT ISLAND PHENOMENON IN TOKYO ON LAND AND SEA BREEZES

Kazuyuki Takahashi[1),2)], Takehiko Mikami[3)], Hideo Takahashi[2)]
[1)] Tokyo Metropolitan Research Institute for Environmental Protection, Tokyo, Japan;
[2)] Tokyo Metropolitan University, Tokyo, Japan; [3)] Teikyo University, Tokyo, Japan

Abstract

This study analyzed the influence of the urban heat island (UHI) in Tokyo on land and sea breezes based on the observational data in two summers. Wind speed of northerly land breeze that observed late at night decreased clearly between the center of Tokyo and the coastal area. It means that the stagnation of land breeze front occurred due to the UHI in Tokyo. Consequently, a calm zone or convergence zone was formed in the leeward side of the center of Tokyo at that time. The calm zone, which coincided with a low pressure area, formed not only on land and sea breezes days but also on weak wind days, regardless of a hot or a cool summer.

Key words: Urban Heat Island, land and sea breezes, convergence, calm zone, low pressure, METROS

1. INTRODUCTION

Spatial extent and intensity of UHI vary in accordance with the time of day, larger scale atmospheric environment, and urban structure (Oke, 1987). In a coastal city such as Tokyo, interactions between land and sea breezes and UHI are expected.
In Japan, many investigations have been conducted concerning the relationship between the land and sea breezes and UHI in the metropolitan area including Tokyo. However, many studies depended on the observational data of which density is not necessarily enough, or on a numerical simulation. Few studies have analyzed the relationship between the land and sea breezes and UHI in Tokyo by using higher density observational data than AMeDAS (Automated Meteorological Data Acquisition System) of Japan Meteorological Agency.
In order to grasp the minute structure of the UHI in Tokyo, Tokyo Metropolitan Government installed the high density observation system called METROS (Metropolitan Environmental Temperature and Rainfall Observation System) in the Tokyo ward area. The meteorological observation was performed in collaboration with Tokyo Metropolitan University from August, 2002 to March, 2005.
The purpose of this study is to investigate the influence of the UHI in Tokyo on land and sea breezes in summer using the data of METROS. This study especially focused on the behavior of land breeze that relates to the UHI at night.

2. DATA

The location of METROS stations is shown in Fig. 1. The METROS system consists of two kinds of observation systems, METROS20 and METROS100. METROS20 was installed on the rooftop of 20 buildings, and observed wind, temperature, air pressure, and so on. Also, temperature and humidity sensors for METROS100 were installed into the instrument shelters of about 100 elementary schools with spatial density of about one station per 2.5 km x 2.5 km area (the dots in Fig. 1 indicate METROS100). Since the METROS system has only a few stations in the sea and suburban areas, the observation data of "Umi-hotaru" (Japan Ministry of Environment, "◆"), AMeDAS (Japan Meteorological Agency, "●"), and JODC (Japan Oceanic Data Center, "▲") stations were also used (Fig. 2).

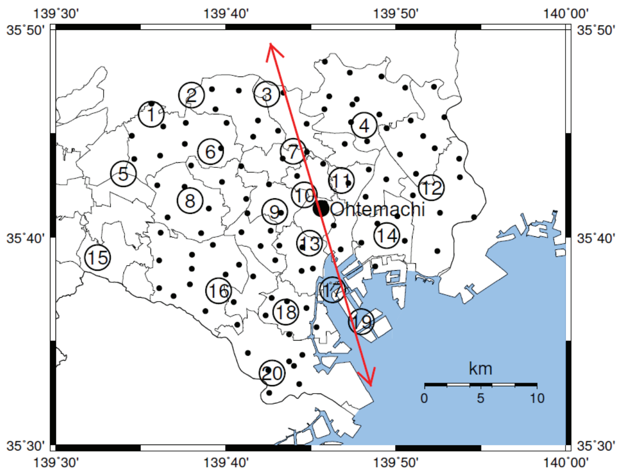

Fig. 1 Location of METROS stations.

3. PERIODS AND DAYS FOR CASE STUDY

This study targeted July and August when the days with suitable weather condition for land and sea breezes were likely to occur, for the years of 2003 (a cool summer) and 2004 (a hot summer).

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*Corresponding author address: Kazuyuki Takahashi,
Tokyo Metropolitan Research Institute for Environmental Protection,
1-7-5 Shinsuna Koto-ku Tokyo, 136-0075 Japan; e-mail: takahashi-ky@tokyokankyo.jp

In order to grasp the interaction between the land and sea breezes and the UHI, we selected typical days in consideration of synoptic conditions, wind system change, and so on. In a hot summer year of 2004, eight days of land and sea breezes days were selected. In these days, three days from July 7 to 9, 2004 when the land and sea breezes days continued were selected for the period of case study.

4. RESULTS AND DISCUSSION

4.1. Case study

4.1.1. Wind direction and speed at each station

Diurnal change in wind vector along the prevailing wind direction of the land and sea breezes (a red line in Fig. 1) in Tokyo was compared. The hodographs at station ③ (northern), ⑩ (central), and ⑲ (coastal) which were averaged for three days from July 7 to 9, 2004 are shown in Fig. 3 (a) - (c). Land breeze was weaker than sea breeze as a whole.
Moreover, wind speed and duration of land breeze at coastal area was much weaker and shorter compared to those at northern and central areas.

4.1.2. Temperature gradient and N-S wind speed

Fig. 4 indicates the distribution of temperatures and wind vectors along the wind direction of the land and sea breezes as shown in Fig. 1 with adding two stations of "Saitama" and "Umi-hotaru" (Fig. 2) at 4:00 AM on July 8, 2004. Air temperature denoted deviation from that at "Umi-hotaru". Relationship between the wind component of north-south direction and average temperature gradient in Fig. 4 is shown in Fig. 5.
Here, positive wind speed indicates southerly wind, and positive temperature gradient means that northern station shows higher temperature.
Fig. 5 indicates a good correlation (significant at 1% level) between the temperature gradients and north-south wind speeds during the period of 0:00 to 9:00 AM when the land breeze appeared at station ⑩ in the center of Tokyo [Fig. 3 (b)].
From Fig. 5, a calm zone is expected around the center of the UHI in Tokyo where the temperature gradient is small at night.

4.1.3. Temperature distribution and wind system in and around the Tokyo Metropolitan Area

Fig. 6 indicates the composite chart of the north-south wind speed and temperature distribution at 3:00 AM averaged for three days from July 7 to 9, 2004.
The temperature distribution is indicated by deviation from area-average of shown area. The mean temperature is shown in the lower left and the color scale shows temperature deviation. A typical UHI occurred in the center of Tokyo. The arrow in the figure expresses the average wind vector for the three days at observation stations. Solid line (red) indicates the north-south wind speed of 0 m/s, and the dashed lines (red) represent that of ±0.3 m/s. These lines show approximate location of the calm zone. The calm zone appeared between the center of the UHI and the coastal area.
Fig. 7 shows the distribution of the divergence and north-south wind speed at 3:00 AM averaged for the three days. The color scale shows the amount of divergence (+) and convergence (-). The thin arrows show spatially interpolated wind vectors. A center of convergence exists in the coastal area of Tokyo, and a divergence center is

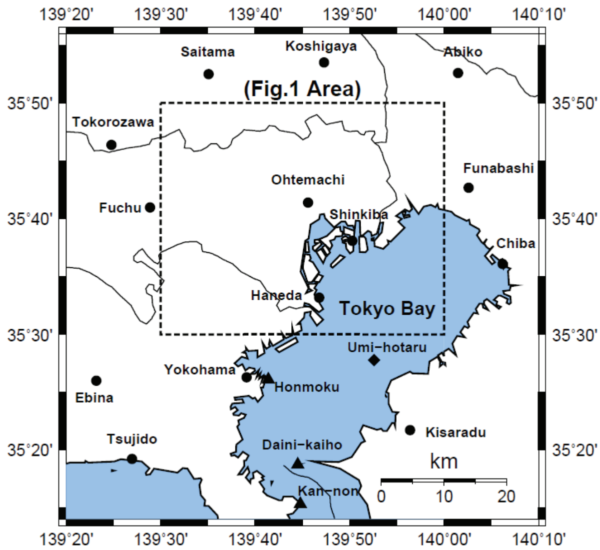

Fig. 2 Location of other stations.

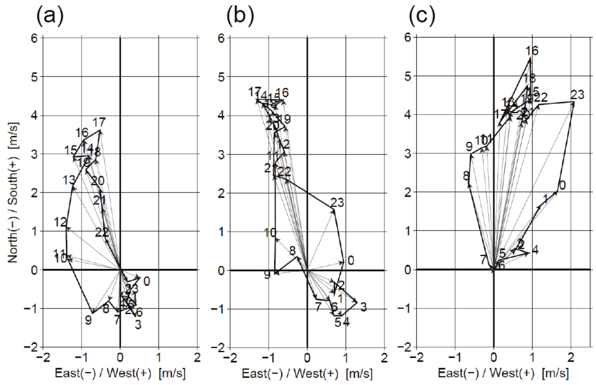

Fig. 3 Hodographs at ③(a), ⑩(b), ⑲(c) station averaged for three days July 7-9, 2004.

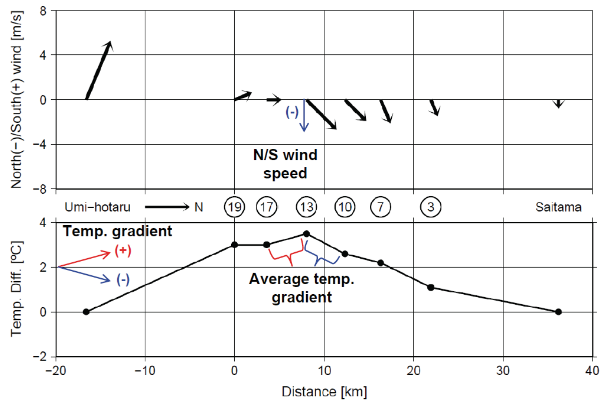

Fig. 4 Temperature distribution and wind vectors at 4:00 AM, July 8, 2004.

seen between "Umi-hotaru" and "Kisaradu". The calm zone and the convergence center mostly overlap, and it is thought that the formation of the calm zone is related to the convergence due to the UHI.

4.1.4. Comparison with early study

By a numerical experiment, Yoshikado (1992) found that the inverse wind system against sea breeze arose due to the high temperature of the city area, and that the inland progress of sea breeze was delayed. It is thought that the nighttime calm zone due to the UHI found in this study is a comparable phenomenon to that clarified by Yoshikado (1992).

Table1 summarized the comparison of this study and Yoshikado (1992). The most noticeable difference is as follows. A sea breeze is strengthened by the temperature rise in the afternoon, and advances into inland. However, a land breeze does not extend to the sea area because it is weak and southerly wind system exists over the Tokyo Bay, to the south of the land breeze. As a result, the calm zone stagnates for a long time.

4.2. Statistical analysis

4.2.1. For 2004 (A hot summer)

The composite chart of the temperature distribution and north-south wind speed at 3:00 AM averaged for eight days of land and sea breezes days in 2004 is shown in Fig. 8. The concentric contours (black) indicate isotherms. A typical UHI occurred in the center of Tokyo. As same as the case study, the calm zone appeared between the center of the UHI and the coastal area, and the high temperature area stagnated at the almost same location.

The composite charts averaged for 20 days of weak wind days in 2004, when the average wind speeds at night were less than 1.0 m/s, were drawn (figures are omitted). It was found that the calm zones due to the UHI were seen not only on the land and sea breezes days but also on the weak wind days.

4.2.2. For 2003 (A cool summer)

The composite charts averaged for three days of land and sea breezes days, and averaged for 27 days of weak wind days in 2003 were drawn (figures are omitted). The results were the same as those of 2004. The calm zones due to the UHI were seen not only in a hot summer, but also in a cool summer.

4.3. The latest analysis

Although the METROS system observed air pressure, the air pressure distribution in Tokyo was not shown until now due to the instrument errors. Recently, we have succeeded showing the air pressure distribution by correcting the air pressure data. The correcting method is to detect the pressure difference between Ohtemachi and each station under calm conditions at night by assuming hydrostatic equilibrium.

Fig. 9 is the composite chart of the corrected pressure

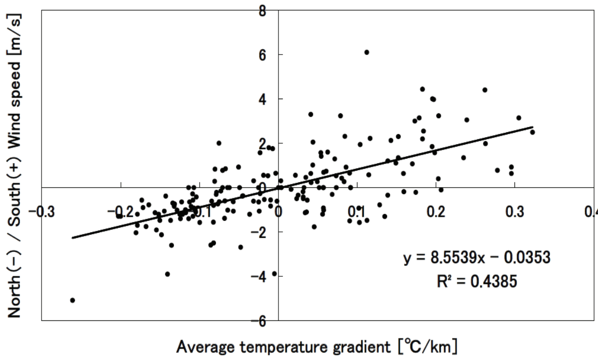

Fig. 5 Temperature gradient and N-S wind speed during 0:00-9:00 AM, July 7-9, 2004.

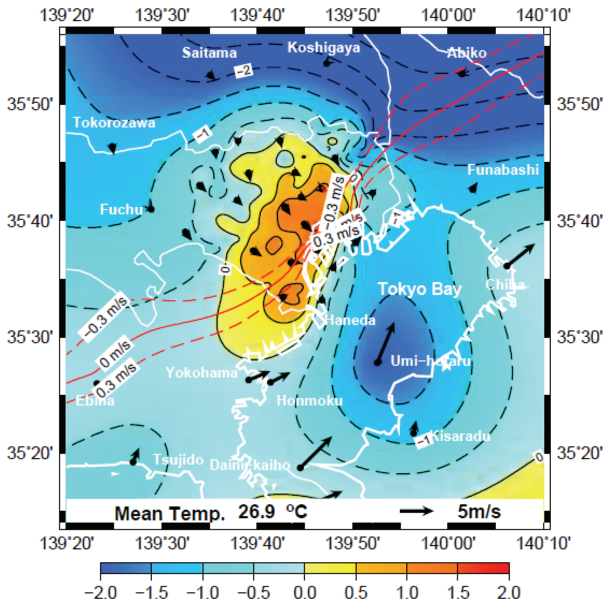

Fig. 6 Temp. distribution and calm zone at 3:00 AM averaged for the three days.

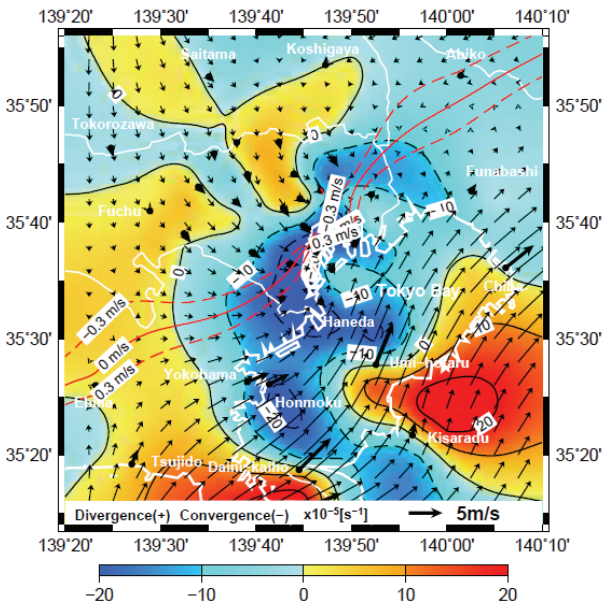

Fig. 7 convergence and calm zone at 3:00 AM averaged for the three days.

distribution and wind vectors at 3:00 AM averaged for three days from July 7 to 9, 2004. The contour interval is 0.1hPa. The pressure distribution is almost consistent with the wind vectors. A closed contour of -0.1hPa is seen in the coastal area corresponding to the center of convergence.
In the future, we are going to analyze the relationship among air temperature, air pressure, and wind system.

Table1 Comparison with Yoshikado (1992).

	This study	Yoshikado (1992)
Progressing wind system	Land breezes	Sea breezes
Inverse wind system	Southely wind which blows south side of the UHI	Northely wind which blows from inland area toward the UHI
Location where the front stagnates	Coastal side of the city	Inland side of the city
Time when the front stagnates	From midnight to early morning	From late in the morning to the afternoon
Behavier after the front stagnated	Land breeze does not extend to the sea area, and a calm zone stagnates for a long time	Sea breeze advances into inland being strengthened

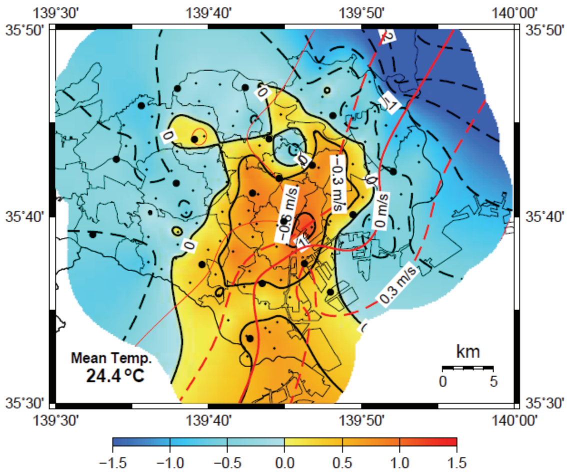

Fig. 8 Temperature distribution and calm zone at 3:00 AM averaged for eight land and sea breezes days, 2004.

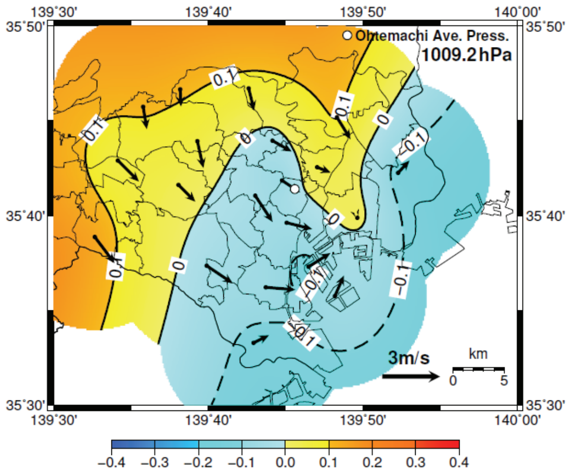

Fig. 9 Corrected air pressure distribution at 3:00 AM averaged for the three days.

5. SUMMARY AND CONCLUSIONS

The results of this study are summarized as follows.
1) It was found that the wind speed and duration of land breeze at coastal area was much weaker and shorter compared to those at northern and central areas.
2) From the relationship between the average temperature gradient and the north-south wind speed, a calm zone was expected around the center of the UHI in Tokyo where the temperature gradient is small at night. The existence of the came zone was confirmed by the case study on the typical land and sea breezes days. It is thought that the formation of the calm zone is related to the convergence due to the UHI.
3) It was found that the calm zone formed not only on land and sea breezes days but also on weak wind days, regardless of a hot or a cool summer. The appearance days were about 1/3 in July and August, 2004, and about 40% in 2003. It was found that the phenomenon generally exists in Tokyo in summer.
4) We succeeded showing the air pressure distribution in Tokyo by correcting the air pressure data by assuming hydrostatic equilibrium. It was found that a low pressure area existed in the coastal area which was the center of the convergence.

References

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