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INLAND AIR-HEATING INDUCED BY A SEA-BREEZE PENETRATION

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Abstract

To clarify the heating mechanism of Nara Basin in Japan, we simulated local circulations developed over the Kansai area, with mesoscale meteorological numerical model, WRF. Since Osaka Prefecture is more urbanized than surroundings, the urban canopy structure and anthropogenic heat emission will affect not only the local thermal environment there but also the mesoscale atmosphere of surroundings. Our simulations revealed that the two heating mechanisms: a dry-foehn phenomenon due to the dry adiabatic process with the mountain-passing sea breeze, and a sensible-heat transport from Osaka urban area by the sea-breeze penetration. These effects induced the air-heating at Nara Basin about 0.5~2.0℃.

Key words: sea breeze, heat transport, Osaka Plain

1. INTRODUCTION

The Kansai area (Fig.1) of Japan, which includes Osaka, Kyoto, and Nara Prefectures, is an interesting field which two sea-breezes penetrate inland from Osaka Bay: one penetrates into the northeastern Kyoto Basin through a plain, the other does into the eastern Nara Basin through over a mountain (600 m in height). Features of these sea breezes have been investigated by Iishii et al. (2000), Ohashi and Kida (2002; 2004), Yamazaki (2004) and so on, using a numerical model. Athough the dynamics of sea-breeze circulations were clarified by these studies, no simultanous comparison have been discussed yet. Therefore, the role of each sea breeze on the climate of Kansai area sould be distincted through the comparison between two sea-breeze. Especially, the sea breeze through over Mt. Ikoma plays an important role of the climate in Nara Basin where a typical basin climate is formed.

Using a meso-scale meteorological model, we investigated the effect of sea-breeze which penetrated into Nara Basin on the basin temperature, as the first step of our aims.

2. AIR-HEATING DUE TO SEA BREEZE DETECTED FROM METEOROLOGICAL DATA

We measured surface air-temperature at some sites during the period of summer season, July 27 to August 17 in 2007. As shown in Fig.1, the two lines were assigned for observation; the “KH (Keihan) LINE” is along Osaka and Kyoto points, and the “I (Ikoma) LINE” is along Osaka and Nara points. Figure 2 indicates that the temporal variations of surface air-temperature measured over the I LINE on (a) non-sea-breeze day and (b) sea-breeze day. The temperatures were averaged every 10 minutes and separating non-sea-breeze and sea-breeze days during the observation period. The daytime temperature measured at the site of I③, which is located within Nara Basin, was lower than those of I① and I② on non-sea-breeze day, whereas the temperature of I③ became the highest of the three sites on sea-breeze day; this feature was detected after the arrival time of sea breeze. Thus, the sea breeze, which penetrated into Nara Basin through over Mt. Ikoma, seems to rise the Nara temperature.

On the other hand, the daytime maximum temperatures at the sites of KH LINE (Fig.3) were delayed with inland on sea-breeze day, whereas no such a feature appears on non-sea-breeze day.

The above features were also confirmed from the AMeDAS (Automated Meteorological Data Acquisition System) stations which were established by Japan Meteorological Agency.

3. NUMERICAL MODEL

3.1. WRF

We used a numerical meteorological model, WRF (Weather Research and Forecasting model) -AWR Ver. 2.2 which was developed by NCAR and so on. The WRF is a compressible fluid and non-hydrostatic model. The Noah-LSM (Chen and Dudhia, 2001) is adopted as a land surface model, which includes plant and urban canopy layers (Kusaka et al., 2001). The TKE prognostic equation (the Mellor-Yamada-Janjic scheme; Janjic, 2001) is adopted for the parametarization of the atmospheric boundary layer. Also, the Lin scheme (Lin et al., 1983) was chosen for the micropyisic calculations.

The horizontal computational domain was divided into the three, and each domain was connected by the two-way nesting method. The domain, which had a finest mesh (1 km in horizontal), included the Osaka and Kyoto urban areas, and includes 79×91 grids. The initial and boundary conditions were given from the use of the meso-scale objective analysis data and RTG_SST data which were provided by the Japan Meteorological Agency and NCEP, respectively. The calculation started from 20 July, 2007 and ended on 31 August, 2007. Thus, the simulation results during the period of 42 days except the first day were analyzed.

3.2. Treatments of Osaka urban effects

Urban canopy effects are introduced by the single-layer urban model. Because the anthropogenic heat emitted from the Osaka urban area can be neglected to impact the atmospheric heating, we inputted the mesh data of the anthropogenic heat flux estimated from the urban energy consumption. Additionally, we improved the model as that the heat intruded into building rooms (windows and walls) was pumped to the outside atmosphere by air-conditioning operations.

4. SIMULATION RESULTS

Figure 4 shows the temporal variations of surface air-temperatures measured and calculated within Nara Basin. The calculated temperature well corresponds to the measured that, especially compared with the simulation case without urban canopy and anthropogenic heat.

To investigate the urban and mountain effects on Nara temperature, we calculated four assumptions with WRF: ①CASE ALL includes urban canopy layer, anthropogenic heat emission, and real terrain (mountains), ②CASE SLAB without urban canopy and anthropogenic heat, ③CASE FLAT with flat plain without mountains, and ④ CASE NO without all.

Figure 5 indicates the differences in daily maximum temperatures between CASES ALL, SLAB, FLAT and CASE NO, at Nara Basin. The Nara temperature difference between CASE SLAB and CASE NO implies mountain effects; in many days of sea breeze arrival at Nara, the temperatures in CASE SLAB were 0.5℃ or over higher than those in CASE NO. We consider that a dry-foehn appears due to a descending sea breeze from Mt. Ikoma. On the other hand, the temperature difference between CASE FLAT and CASE NO represents an influence of the Osaka urban heat transported by sea breeze on Nara temperature. In the almost sea-breeze days at Nara, the temperatures in CASE FLAT were 0.5~1.5℃ higher than those in CASE NO. This heating at Nara is induced by the horizontal advection of the Osaka urban heat. Finally, the temperature difference between CASE ALL and CASE NO is provided by the above both works. The temperatures in CASE ALL were higher than those in CASE NO in all sea-breeze days. Additionally, these temperature differences were, to some extent, higher than those between CASE FLAT and CASE NO. It is worthy of note that the temperature differences between CASE ALL and CASE NO become to be smaller than sum of “CASE SLAB minus CASE NO” and “CASE FLAT minus CASE NO.” That is, the coexistence of the Osaka urban area and Mt. Ikoma weakens the air-heating at Nara Basin. This results from the fact that Mt. Ikoma works as the “wall” which makes the Osaka urban heat transport difficult.

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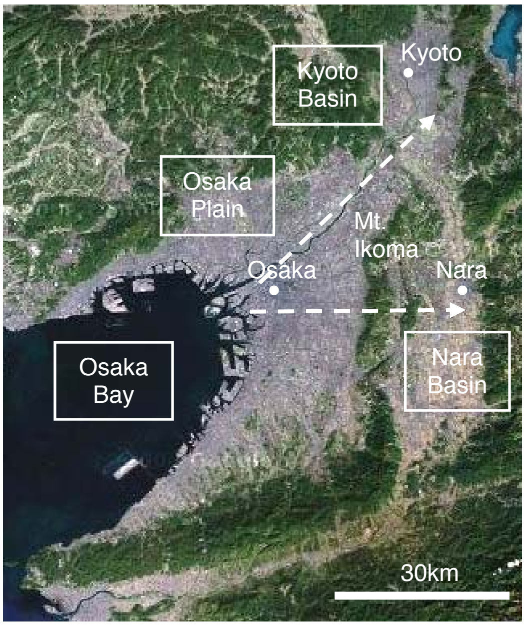

Fig.1 The Kansai area which are a field of our study. The dashed lines indicate a penetration direction of the sea breeze.

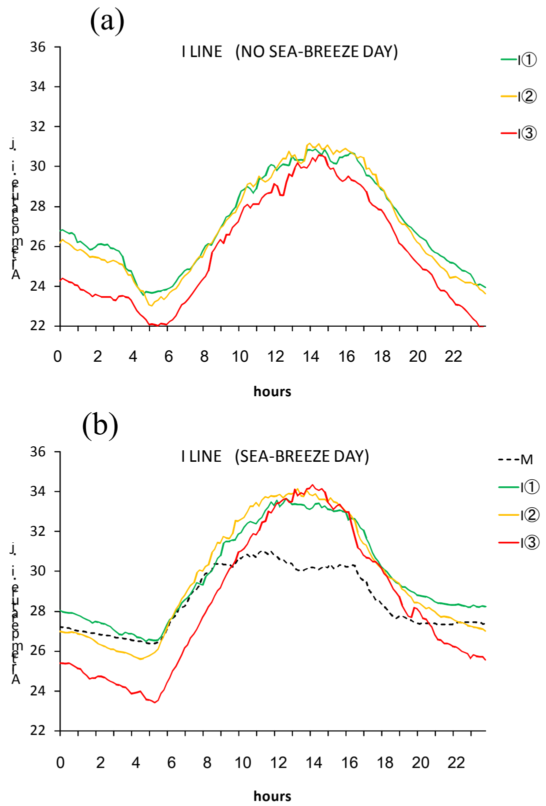

Fig.2 Temporal variations of surface air-temperature measured over the I LINE (Ikoma Line) at (a) non-sea-breeze day and (b) sea-breeze day. The temperatures are averaged every 10 minutes and separating non-sea-breeze and sea-breeze days during our observation period.

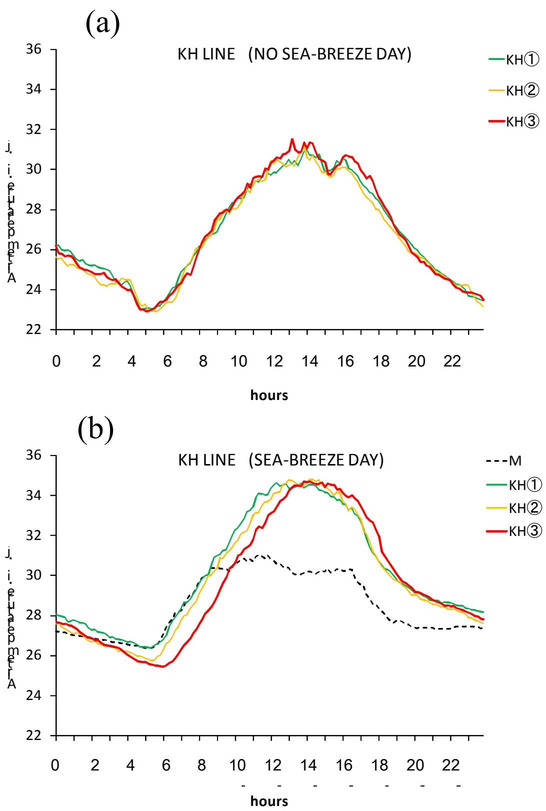

Fig.3 Same as Fig.2 but KH (Keihan) LINE.

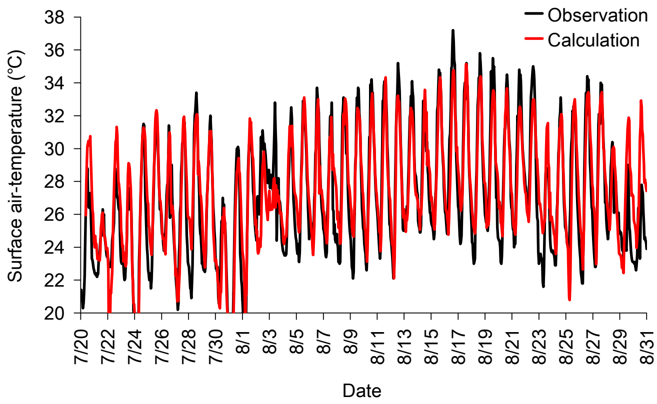

Fig.4 Surface air-temperatures measured and calculated at Nara Basin.

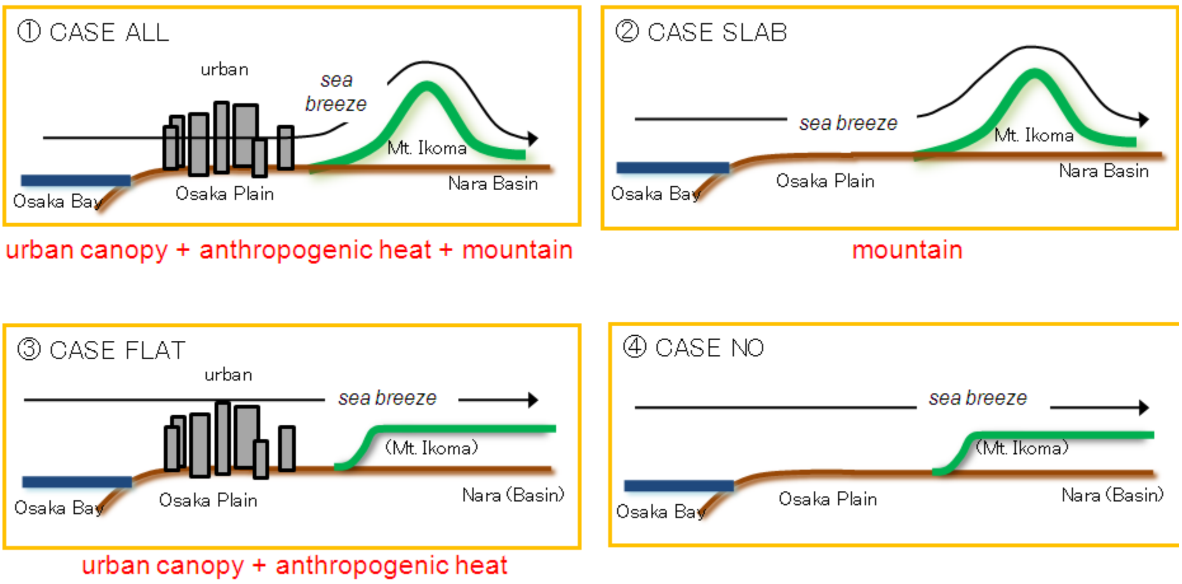

Fig.5 Four simulation cases: ①CASE ALL includes urban canopy layer, anthropogenic heat emission, and real terrain (mountains), ②CASE SLAB without urban canopy and anthropogenic heat, ③CASE FLAT with flat plain without mountains, and ④CASE NO without all.

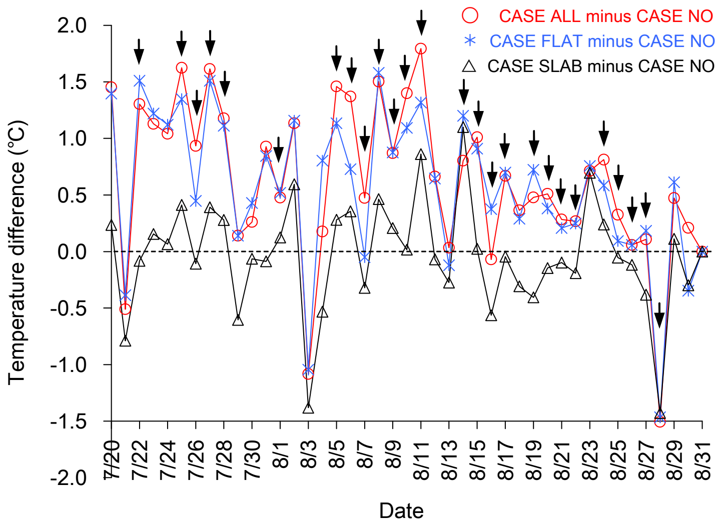

Fig.6 Differences in daily maximum temperatures between CASES ALL, FLAT, SLAB and CASE NO, at Nara Basin. The arrow indicates a day when sea breeze seems to arrive at Nara Basin.