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Relation between the Air Pollution and the Meteorological Condition at Asahikawa

— On the Heat Island Effect —

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Abstract

Horizontal and vertical distributions of temperature in lower atmosphere were obtained by the radio sonde and the traverse through Asahikawa City area. It is found from the observations that in winter Asahikawa City made a typical "heat island" and temperature gradient near the boundary between the urban and the rural regions came to be as large as 6°C/300 m.

A "cross over" layer in which the temperature in the rural region is higher than that in the urban region were found from two observation sites. It is considered that the convection motion existed between both regions.

1. Introduction

In interior of Hokkaido island very low temperature are frequently recorded during the winter season when it is calm and fine. This situation is caused by the penetration of cold air from Sibria and long wave radiation to space in the nighttime. Consequently, strong surface inversion forms in the basins distributed in Hokkaido. The Kamikawa basin is one of them. Air temperatures in the basin drop to -20°C or lower. Asahikawa City is located on the west side of the Kamikawa basin and makes a built-up area. Low temperature air pollution is generated, therefore, in these basins by the exhaust from vehicles, heatings and many factories.

Benson[1] reported that low temperature air pollution at Fairbanks, Alaska located in the northern part of a basin between the Alaska range and the Brooks range associates with the heat island, strong surface inversion and ice fog phenomena.

Existence of the heat island in large cities had been reported by Bornstein[2] at New York, N.Y. and Clarke[3] at Cincinati, Ohio. Bornstein observed air temperature at various heights over New York City and showed clearly a

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"cross over" layer in which temperature of the rural region is higher than that of urban region at the upper part of the inversion.

In this paper, the author will report on the structure of the heat island at Asahikawa according to observations of horizontal and vertical distributions of temperature associating with low temperature air pollution.

2. Measurement

In order to analyze the horizontal distribution of temperature in Hokkaido island, data were collected from meteorological observatories to be distributed in the whole island. Moreover, more detailed analyses were made in the Kamikawa basin by use of records from the meteorological observatories for the agriculture.

Observations of vertical temperature distribution were conducted at the center of Asahikawa City. Radio sonde which consists of electric resistance thermometer and the transmitter was hung under a captive balloon. Observation height was up to 700 m above the ground or lower. But it could not gain sufficiently when the wind speed was high because a spherical balloon was used. Instruments used during the observation are as follows:

Transmitter··········	JWA-76T	(Meisei Elect. Co., Ltd)
Receiver ··········	SAR-2	(〃)
Recorder ··········	EPR-2T	(Toa Elect. Ltd.)

Accuracy in temperature as a system was ± 0.2°C. Height of the balloon was decided by an atmospheric pressure marked at every 10 mb on the recording paper. The accuracy in height was ± 10 m.

In order to obtain the horizontal distribution of temperature around Asahikawa City, a thermistor thermometer placed on the roof of a vehicle was used. The vehicle was driven along the highway (mainly Routes 39 and 40) from the urban to the rural regions.

3. Result

3.1 Horizontal distribution of temperature

In order to confirm cold area in interior of Hokkaido, horizontal distribution of temperature shown in Fig. 1. The isothermal lines were drawn by the use of the mean temperature of January 1979. From the figure, it is seen that the cold area covers the northern and eastern parts of Hokkaido. In these areas, many basins are contained and cold air which is produced by the radiation cooling tends to accumulate in them. On the other hand, a warm region is formed near Asahikawa City. This is just a "heat island" in the cold area.

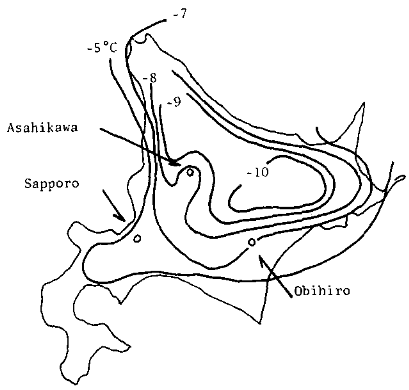

Fig. 1 Monthly mean temperature on January, 1979.

The heat island tends to appear clearly in minimum temperature distribution as is well known. Figs. 2(a) and (b) are the minimum temperature distribution in Hokkaido and in the Kamikawa basin respectively on February 13, 1976. The distribution in Hokkaido is essentially the same with that of monthly mean temperature distribution as shown in Fig. 1. From Fig. 2(b), it is seen that the temperature difference between urban and rural regions was about 4°C. And then an isothermal line approximately agrees with the boundary between urban and rural regions.

Fig. 3 is a distribution of temperature measured by use of a vehicle along the highway of route 40 on February 9, 1979. Although the observation area was a north-east part of the city only, temperature gradient was steep at the boundary between both regions. The temperature gradient reached to 6°C/300 m and temperature in the built-up area was almost uniform. There is another interesting fact that the Ishikari river produces a cold region which penetrates into the urban region. This shows that the cold air inflows toward the urban region along the river near the ground[4].

From these facts mentioned above, on urban region such as Asahikawa City produces a typical "heat island" during the winter season. The temperature difference between the urban and the rural regions was 4 to 6°C and temperature gradient was steep near the boundary between both regions.

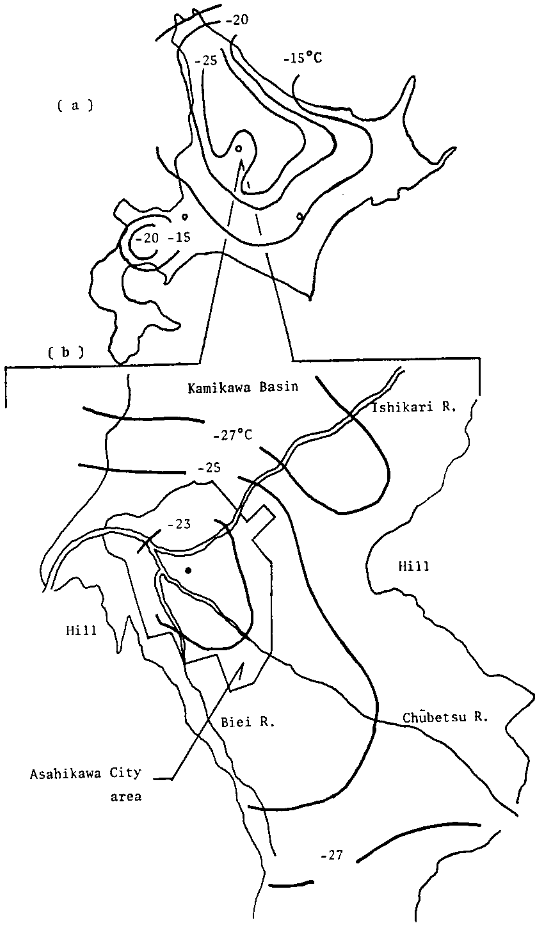

Fig. 2 Distributions of minimum temperature in Hokkaido (a) and in Kamikawa basin (b) on February 13, 1976.

3.2 Vertical structure of lower atmosphere

Analysis of vertical structure in lower atmosphere is of importance to the study of the diffusion of pollution. When a disturbance in the weather system is passing over the observation site, air temperature decreases with increasing altitude. However, in the interior of Hokkaido during the winter season temperature inversion near the ground forms after the disturbance such as the winter monsoon, by which the heavy snow fall is brought, is gone.

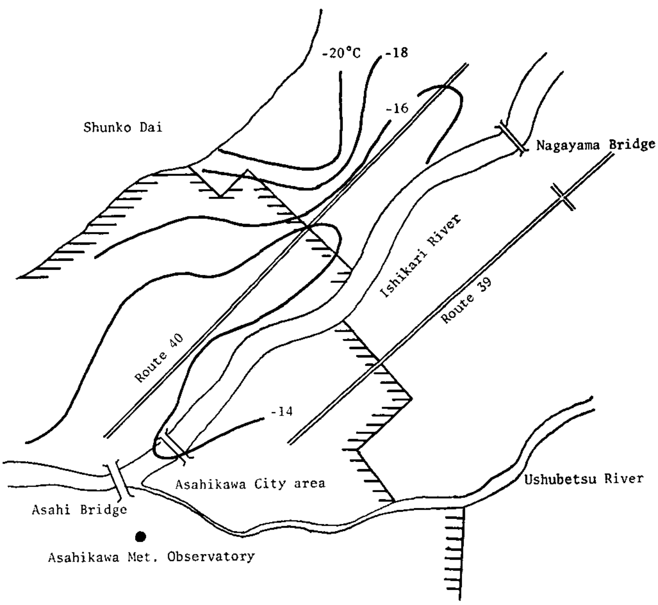

Fig. 3 Distribution of temperature in and around Asahikawa City. Observation was made during the period from 2100 to 2200 February 9, 1979.

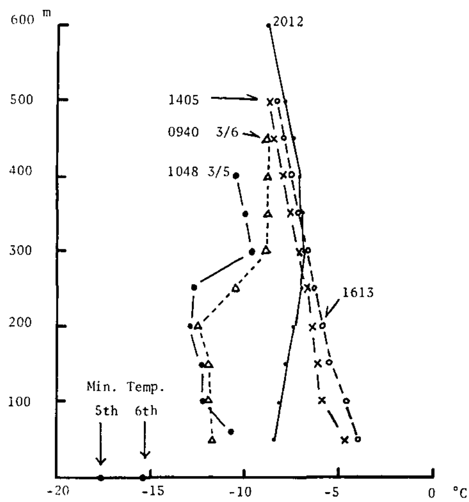

Fig. 4 Temperature profiles observed during the period from 1048 March 5 to 0940 March 6, 1975. Also, the minimum temperatures on the 5th and 6th are marked on the abscissa

Observations of temperature with increasing altitude have been made since 1975. Time change of temperature profiles is shown in Fig. 4 which was observed at 1048 (all times are JST) March 5 to 0940 March 6, 1975. Surface inversion which might be formed on the early morning of the 5th in layer lower than 300 m above the ground was already weakened with the heating by means of the sunrise and begining of human activity. Consequently, a thin inversion was remaining in the layer between 250 and 300 m at 1048 March 5. After that, the inversion disappeared completely with a rising of temperature in the lower atmosphere. Temperature profiles at 1405 and 1613 showed the normal lapse rate. After sunset temperature near the ground decreased gradually. Then the surface inversion formed at 2012 in the layer lower than 300 m in height. Although no observations were made during the night, a temperature profile at 0940 on the 6th was the same as 1048 on the 5th. From these observations, the surface inversions formed during the nighttime and their intensity reached to 8.6°C/300 m.

In order to explain the matter in detail, time change of temperature at every 100 m and time cross section are drawn in Fig. 5. Observations of temperature were made from 1000 February 13 to February 14, 1976. Top of the figure is time change of temperature at surface, 100, 200, 300 and 500 m in height. It is seen from the figure that time change at a height of 100 m resembles that of surface temperature in shape. However, temperatures at height of 300 and 500 m were gradually rising up, even though the surface temperature went down after the sunset. In this case, a thin inversion remained in the layer between 300 and 400 m in height at 1340 on the 13th. Top of the inversions might be about 500 m because the top of inversion from an observation up to 1500 m at 2230 on the 13th was 550 m as shown in Fig. 6, and average intensity and the steepest intensity of the inversions were 2.2 and 4.4°C/100 m respectively.

The bottom in the Fig. 5 is a time cross-section which was made from the observations mentioned above and the isoplets are drawn every 2°C. Near the ground cold air formed in the night disappeared during the afternoon. After that, two warm air regions appeared, one is near the ground at 1500 and another at a height of about 500 m in the night. The latter may be formed by the upward transportation of warm air near the ground because the surface inversion disappeared in the daytime caused by convective motion of air.

There are few observations of horizontal distribution of the temperature

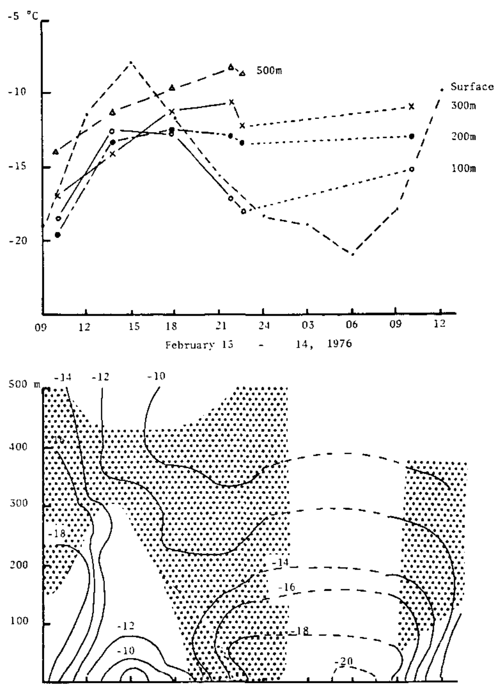

Fig. 5 Time change of temperature (top) and time cross section (bottom). Shadowing area indicates the inversion layer.

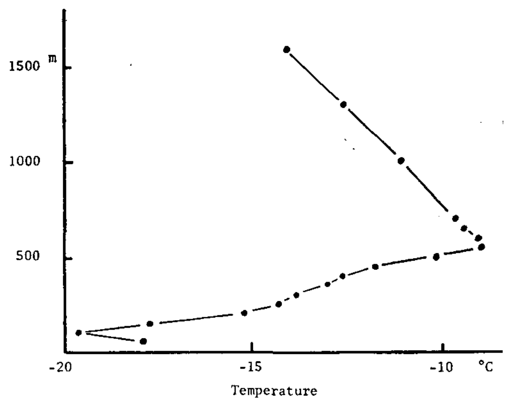

Fig. 6 Temperature profile at 2230 February 13, 1979.

profiles in Hokkaido. In this paper, a result of the comparison of temperature profiles from two observation sites is reported as shown in Fig. 7 (a) and (b). The observations were made during the period from 0927 to 1024 February 24, 1979. The profile at the Nagayama bridge, which is located in a rural region at 7 km northeast of the city center, shows the typical surface inversion. On the other hand, at the city center (built-up area) the layer between 150 and 250 m is the elevated inversion and the layer lower than 150 m came to be adiabatic lapse rate. Vertical distribution T_A-T_N where T_A is the temperature in Asahikawa and T_N in Nagayama is shown in Fig. 7 (b). Difference T_A-T_N is 4.3°C at 50 m in height. It is evident that the heat island formed near the ground. Also, T_A-T_N decreases with increasing altitude and at a height of 200 m reachs to –2.6°C. Namely, it is clearly a "cross over" effect[2]. Above 250 m in height the T_A-T_N is almost constant. This fact allow the estimation of the existence of convective motion between both regions.

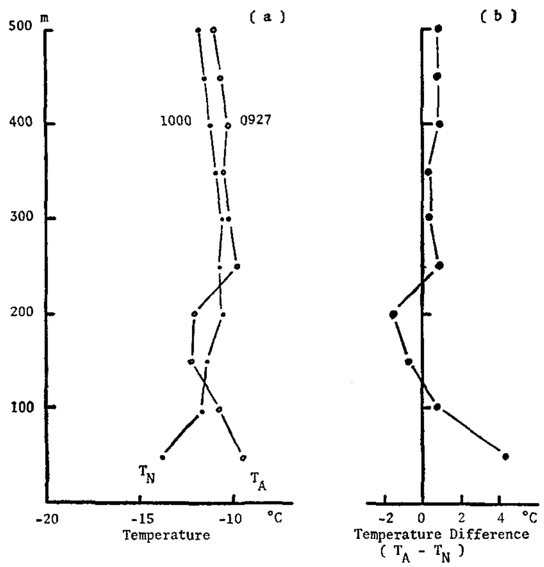

Fig. 7 Temperature profiles (a), T_A: Asahikawa as the urban region. T_N: Nagayama as the rural region. Temperature difference (b), T_A-T_N, on February 24, 1979.

4. Consideration

Fairbanks, Alaska has the same condition as Asahikawa. Benson[1] carried out the observations about vertical and horizontal temperature distribution and air pollution at Fairbanks. He reported that the surface temperature difference between urban and rural regions reached to 7°C December 13, 1964 and obtained the mountain shaped pattern as horizontal temperature variation by traverse through Fairbanks City. The variation is, however, remarkably different from that in Asahikawa City. Namely, rising of temperature from rural to urban regions is gradual at Fairbanks and there was not considerable temperature difference as observed in Asahikawa. This discrepancy may be dependent on the difference of housing distribution because at Fairbanks the boundary between both regions is not clear. Moreover, he pointed out that the heat island effect is not sufficient to destroy the inversion which forms close to the ground during the long nighttime.

The horizontal distribution of temperature depends on the shape of the built-up area, the highway and the river. The highway becomes a heat source caused by the exhaust-gas from the vehicle. On the other hand, the river whose surface is covered by the ice pack in winter acts as a heat sink. It acts, also, as a route of the inflow of cold air from rural to urban regions.

Strong surface inversion formed in the night is characteristic and of importance concerning the air pollution problem in cold regions. Benson reported particularly that the strenght of inversions measured during cold spells at Fairbanks was values of 10 to 30°C/100 m, common in the first 50 to 100 m above the ground. At Asahikawa, the strenght of inversions ranged from 1.7 to 4.0°C/100 m. As to the steep inversion at Fairbanks, Benson explained that Fairbanks is surrounded by hills on three sides which permits stagnant air.

Diurnal range of temperature near the top of inversion is smaller than that near the ground and maximum temperature appears at 2000 to 2200. Moreover, there are two warm regions from the time cross-section of vertical distribution of temperature, that is, one is near the ground in the daytime and another near the top of inversion in the nighttime. It is suggested that the warm air near the ground transported upward by the convective motion.

As a characteristic of the heat island, there is a "cross over" effect[2),5)]. In Asahikawa, a typical cross over effect was recognized by the comparison with two temperature profiles, one obtained at urban site and another at rural site. To compare with the cross over layer in Asahikawa and New York, the following table was made:

Table 1.

Location	Asahikawa	New York*
Base of layer (m)	120	305
Depth of layer (m)	120	180
Level of maximum rural excess (m)	200	370
Maximum rural temperature excess (°C)	1.6	0.8
Temperature difference between both sites at 50 m (°C)	4.3	1.5

*After Bornstein[2)]

From the table, it is seen that height and depth of cross over layer were lower and shallower in Asahikawa than in New York respectively. On the other hand, temperature excesses of the urban region near the ground and of the rural region in cross over layer were together higher in Asahikawa than in New York. These larger temperature excesses predicted the possibilities of strong convection current between the urban and the rural regions.

5. Conclusion

From the observations the followings may be concluded:

(1) A typical heat island is formed in the Asahikawa City area during the cold season.

(2) Surface inversions form in the rural regions as well as in the urban regions in the nighttime.

(3) In the urban region, the surface inversion disappears in the daytime. However, there are a few cases in which elevated inversion remains in the daytime.

(4) In the upper part of the inversion, diurnal variation of temperature is small and maximum temperature is recorded in the nighttime.

(5) From the observations of temperature profiles at the two sites, the existence of cross over layer is confirmed. Therefore, it is considered that the strong convective current exists between both region.

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