SOME CONSIDERATION ON SURFACE WINTER TEMPERATURE FIELDS IN THE KANTO PLAINS, CENTRAL JAPAN

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Abstract The division of the winter surface temperature fields was made in terms of estimated population means. And peculiar regional difference was confirmed to appear in minimum temperature field of the northern part of the plain. This peculiar regional difference was found to be caused from both the difference in the thermal characteristics of air and in strength of forced convection.

1. General Introduction

The development of synoptic climatology introduced by Jacobs (1946, 1947) has brought a new phase to meso-scale climatology. Those studies showed that spatial patterns of climatic elements as well as values of climatic elements at each place differ under different conditions of gradient winds, pressure patterns or other factors. As a result, synoptic climatology can describe dynamical climate compared with the so-called classical climatology. And it was found that a mean of certain climatic data used in the classical climatology is a mean of different samples drawn from different populations. A certain cluster of climatic data is thought to be composed of samples drawn from different populations. So a sample of climatic data must be drawn under the conditions of gradient winds, pressure patterns or other factors.

Several investigations have been undertaken about meso-scale climate in the Kanto Plains, the largest plain in Japan, bordering on the Pacific Ocean. By the way, in synoptic climatological investigations taking the Kanto Plains as a study area since Maejima (1954), different conditions of gradient winds, pressure patterns or other factors have been adopted by different investigators. There are no investigations which evaluate the conditions. However, evaluation of sampling conditions is important to recognize climatic phenomena. Therefore one kind of sampling conditions under which samples will be drawn was determined (Hohgetsu, 1978); the surface pressure patterns in East Asia (Yoshino & Kai, 1974). In this kind of sampling conditions, there are several items, that is, the winter monsoon type, the migratory high type, the trough type and others.

About surface winter temperature fields in the Kanto Plains, where dry and fine weather is well known to be predominant in winter, some investigations have been pursued. Kayane (1965), Yoshino (1970) and Japan Meteorological Agency (1977) suggested existence of regional difference in the temperature fields of the Kanto Plains: From the northwestern to the southeastern parts of the plain there appears a region of high daily minimum temperature compared with its surroundings.

In case of delimiting the field of a certain climatic element or climatic index, the following method has been usually adopted as done for instance by Yoshino (1967) who made climatic division of Kanto District. Taking a case of field of mean temperature as an example, boundaries in the field are defined to be existed at places where spatial density of isotherm is high in an isothermal map. By the way, temperature is thought to show temporal variations peculiar to respective places. So when an isothermal map is drawn based on mere sample means, boundaries defined by abovementioned manner may change according to samples. Invariable boundaries must be vital to grasping invariable aspects of the temperature fields. Invariable delimitation of the fields of the plain has not been made yet. And also causes leading invariable regional difference has not been discussed. So in this investigation the author intended to confirm invariable regional difference in surface winter temperature fields of the whole plain. And then the author will discuss mechanism causing invariable regional difference in the temperature fields of the northern part of the plain.

2. Divisions of the Temperature Fields in the Plain

Introduction

In case temperature field is divided by mere sample statistics such as sample means, division of the field may be different for different samples. It may be significant to obtain invariable regional difference in the field. When temperature fields to be divided are on macro scale, invariable division of the fields may be obtained by testing correlation coeffients as Sekiguti (1959) studied. He tested correlation coefficients to check parallelism in climate and divided the climate of Japan. In a meso-scale plain like the Kanto Plains, however, dividing temperature fields by testing correlation coefficients may be difficult, because in general temperature at neighbouring stations on a plain highly correlate. In this chapter invariable division of the temperature fields in the Kanto Plains is confirmed based not on mere sample means but on population means estimated by statistical inference.

Data and Method

The study area of the Kanto Plains is divided into units which have a certain extent. Then based on the spatial distribution of temperature, each of the units is identified with two categories of areas. One is an area where temperature is the same all over the place, and the other is an area where temperature is different at different places. The division of the temperature fields of the Kanto Plains is made through the identification of the units. The above is an outline of the method.

The following is an illustration of the actual procedure for dividing temperature fields: In Figure 1, triangles formed by solid and broken lines correspond to units. These lines form a triangular network over a study area. The reason why units should be triangles was stated by Hohgetsu (1980). Open cirlces at apexes of the triangles are points where data of temperature are available. At each pair of points combined by solid or broken lines, for example a pair of points A and B, two population variances and means estimated under the same item of the sampling conditions are tested by F and "student-t" tests, respectively.

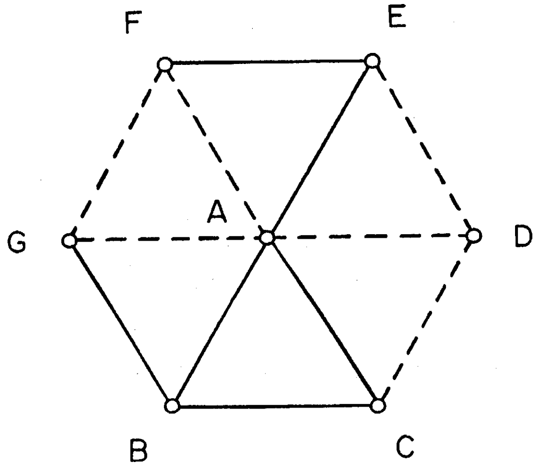


Fig. 1 Schematic illustration to set up statistical boundaries in surface temperature fields
A-G are points
Broken line connects points at which means are significantly different each other
Solid line connects points at which means are not significantly different each other
AB, BC and CA are statistical boundaries

The tests are two-tailed tests and significance levels are set at 1%, 5% and 10%. Here the null hypotheses for F and "student-t" tests are that under the same item of the conditions the population variance and mean at one point are equal to those at the other point, respectively. In Figure 1 two points at which population means are significantly different each other are combined by a broken line, on the other hand two points are combined by a solid line when population means are not significantly different each other. A triangle whose three points are combined by solid lines is only triangle ABC in the figure. It is thought that mean temperature is not different at any places in triangle ABC, but in the other triangles mean temperature is different at different places. Such estimates of temperature distribution are discussed later on. As a result, a study area in Figure 1 is divided into two regions, that is, a region of triangle ABC and a region of the other triangles.

The data of temperature used here are daily maximum, minimum and range of temperature at seventy-eight stations almost evenly distributing on the Kanto Plains (Figure 2), and the cluster of the data is the temperature of three winters (months of December, January and February) from 1961 to 1964, 271 days in all, and these data are the same that used for evaluating the sampling conditions (Hohgetsu, 1978). Nodal points in the triangular network of Figure 2 correspond to the seventy-eight stations, and this network indicates pairs of stations where population means are tested. Based on the results of the previous investigation (Hohgetsu, 1978), division of the temperature fields of the Kanto Plains is confirmed only in the case of three items in the conditions of the pressure patterns, that is, the winter monsoon type, the trough type and the migratory high type.

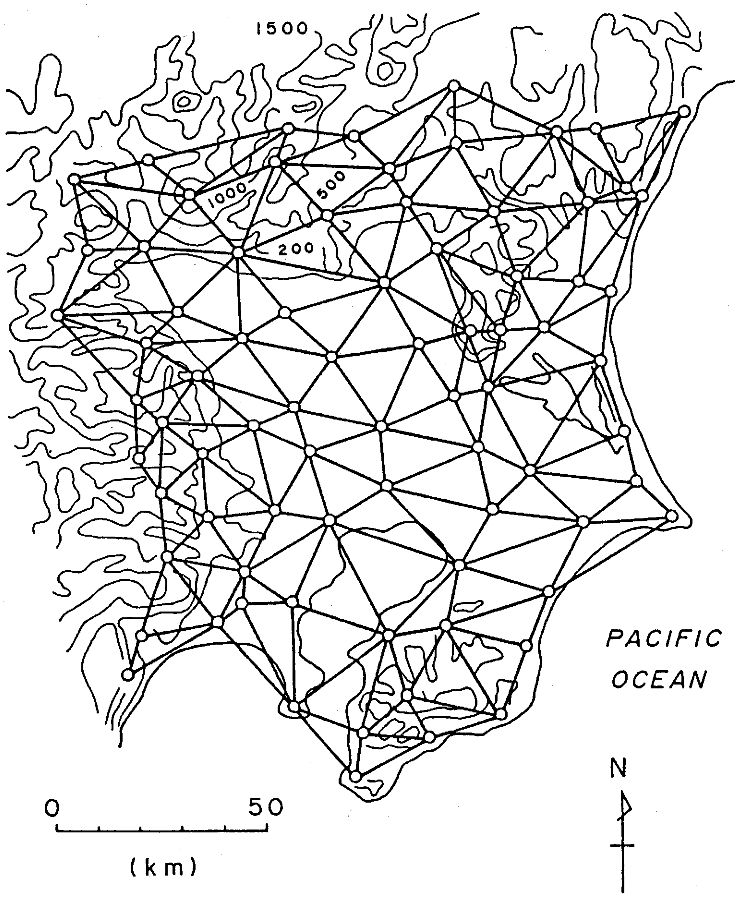


Fig. 2 Locations of the seventy-eight stations, and triangular network of the stations

Results

Hereafter units where mean temperature is in terms of probability not different at any places are called "homogeneous areas", on the other hand units where mean temperature is in terms of probability different at different places are called "heterogeneous areas". The results are described according to the kind of temperature, namely maximum, minimum and range of temperature.

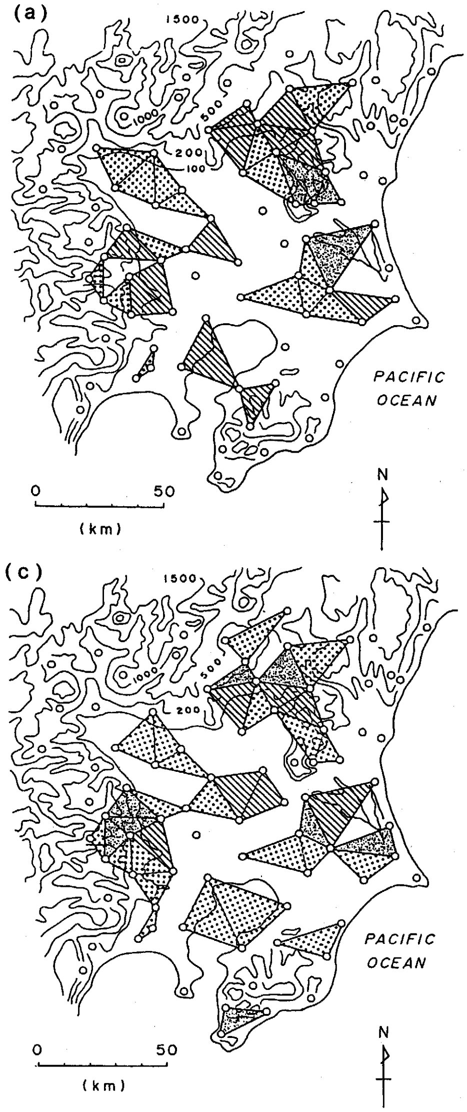
Maximum temperature

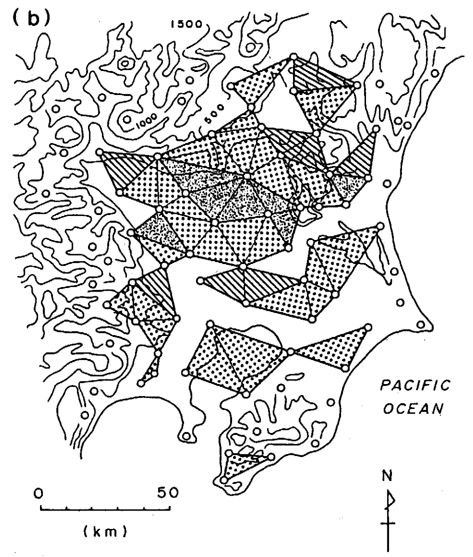
Under the winter monsoon type, "heterogeneous areas" appear in the southern part of the plain at the levels of 10%, 5% and 1%. Under the other types, "heterogeneous areas" appear in the southeastern part at the level of 10%, but these "heterogeneous areas" turn to "homogeneous areas" at the significance levels of 5% and 1%. Any "homogeneous areas" scarcely appear in mountainous regions to the north and the northeast of the plain, and this is particularly distinct in the case of the winter monsoon type. In general "homogeneous areas" extensively appear in the plain and "heterogeneous areas" appear in mountainous regions on the outskirts of the plain, irrespective of type of the pressure patterns.

Minimum temperature

The distribution of "homogeneous areas" under the three types is respectively shown in

Figure 3-a, b, c. At the significance level of 10%, the number of units identified as "homogeneous areas" is small under both the winter monsoon and the migratoy high types as compared with that under the trough type. Under the winter monsoon and the migratory high types, "homogeneous areas" separately appear, roughly speaking, at three regions at all the significance levels. One is a region along the Tone River flowing from northwest to southeast in the plain. The other two are a mountainous region on the west of the plain and a region at the foot of mountains in the northeast of the plain. The first and the last of these three regions are called hereafter Tone region and NE region, respectively. Under the trough type, "homogeneous areas" appear in Tone region and in a mountainous region in the northern part of the plain.





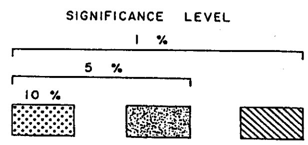


Fig. 3 Distributions of "homogeneous areas" in the case of minimum temperature
(a) the winter monsoon type (b) the trough type (c) the migratory high type

Considering the method of the identification, it is axiomatic that both the number of units identified as "homogeneous areas" and respective lumps of "homogeneous areas" may be large at high significance level compared with those at low level. Under the trough type "homogeneous areas", which separately appear at NE region and the northwestern part of Tone region at the level of 10%, link together at the significance levels of 5% and 1%, and consequently form a lump of "homogeneous areas" in the middle of the northern part of the plain. Under the other types, however, "homogeneous areas" at NE region and Tone region never link together even at the significance level of 1%. Figure 3 shows that "homogeneous areas" appear at these two regions, and that "heterogeneous areas" clearly appear between these regions under the winter monsoon and the migratory high types.

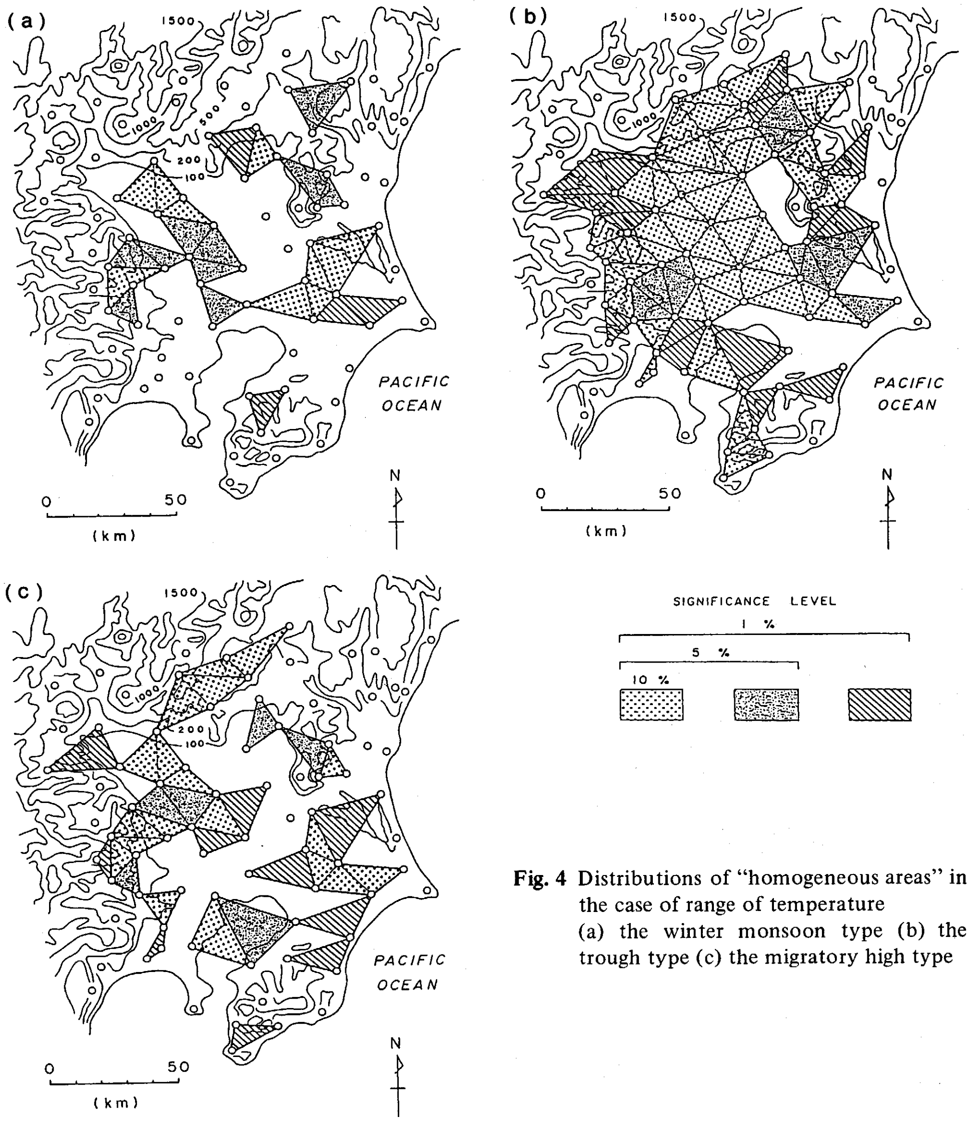


Fig. 4 Distributions of "homogeneous areas" in the case of range of temperature
(a) the winter monsoon type (b) the trough type (c) the migratory high type

Range of temperature

The distribution of "homogeneous areas" under respective types is shown in Figure 4-a, b, c. Under the trough type, a large lump of "homogeneous areas" appears in the middle of the plain including Tone and NE regions even at the significance level of 10%. On the other hand under the other types, "homogeneous areas" appear at NE region and Tone region, and "heterogeneous areas" intervene among these "homogeneous areas". In addition, under all the types, "homogeneous areas" appear at the foot of mountains on the west of the plain. In the result lumps of "homogeneous areas" are much large under the trough type, as compared with those under the other two types.

Thermal characteristics of the temperature fields in the northern part of the plain

It was found in the preceding section that "homogeneous areas" tend to appear at Tone region and NE region, intervened by "heterogeneous areas", and this is outstanding in the case of minimum temperature. In this section thermal characteristics of the temperature fields are further examined, based on interval estimates for means at some stations in the northern part of the plain.

Figure 5 shows some interval estimates for means at the confidence level of 90%. The figure shows a trend that population means of maximum temperature change from low to high following a series of the winter monsoon type, the trough type and the migratory high type. On the one hand, there exists no distinct regional difference in population mean of maximum temperature irrespective of the types. This is compatible with the fact found in the previous section that a large lump of "homogeneous areas" appears widely in the middle

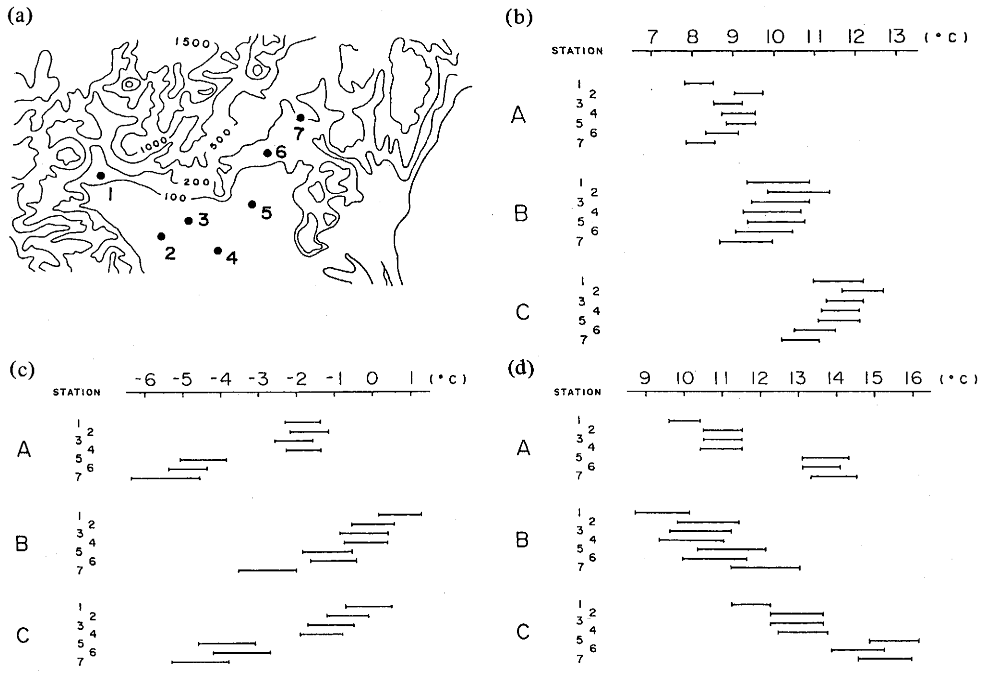


Fig. 5 Interval estimates for means at confidence level of 90%
A: the winter monsoon type B: the trough type C: the migratory high type
(a) locations of stations (b) maximum temperature (c) minimum temperature
(d) range of temperature

of the plain in the case of maximum temperature.

Figure 5 also shows that population means of minimum temperature at the "homogeneous areas" of Tone region are the lowest under the winter monsoon type and the highest under the trough type, and those of NE region are the highest under the trough type. As to regional difference, population means of minimum temperature are higher at Tone region than at NE region under the three types, especially the winter monsoon type. Under the winter monsoon type, this relation stands even at the confidence level of 99%. This is compatible with the fact found in the preceding section that the lumps of "homogeneous areas" at Tone region and NE region are distinctly intervened by "heterogeneous areas" under the winter monsoon type. Several investigations previously reported that sample means of minimum temperature at Tone region is higher than those at NE region. Those results agreed with the results obtained in this investigation using interval estimates for means. A large lump of "homogeneous areas" appears at the level of 1% in the middle of the plain under the trough type. This is compatible with the fact that under this type the interval estimates at Tone and NE regions overlap one another at the confidence level of 99%, and consequently no distinct difference in thermal characteristics can be found between these regions.

In the case of range of temperature, population means under respective types vary from region to region. At Tone region population means of range of temperature are smaller under the winter monsoon and the trough types equivalently than under the migratory high type. On the one hand at NE region, there is a trend that population means of range of temperature becomes larger following a series of the trough type, the winter monsoon type and the migratory high type. Under the three types, population means of range of temperature at Tone region is smaller than at NE region. This is noticeable under the winter monsoon type.

The identification of units with "homogeneous areas" and "heterogeneous areas" in the northern part of the plain is properly confirmed by the examination of the thermal characteristics based on the interval estimates for means.

Discussion and Conclusion

Division of the temperature fields in the Kanto Plains was confirmed based on population means estimated by a method of statistical inference. As the result, peculiar regional difference was found in the fields of the northern part of the plain, and moreover it was found to be remarkable in the case of minimum temperature. Then thermal characteristics in this part of the plain were further examined. As a result, it was found that thermal characteristics in the fields are different under different types of pressure patterns. It is particularly noticeable that population means of minimum temperature are high at "homogeneous areas" of Tone region and those at "homogeneous areas" of NE region are low as compared with their surroundings under the winter monsoon type.

There is by no means spatially sudden variation of surface temperature at certain lines like those organizing the network in Figure 2. Therefore each "homogeneous area" never corresponds to a whole area of equal population mean but only to a core of such an area.

If distance between neighbouring two stations varies according to pairs of stations, the sizes of the units will be different one another. When the sizes of respective units are different one another, there probably happens clumsiness that jumbles of various features of the temperature fields, in extreme cases features on micro- and meso-scale, are got despite the purpose of grasping the features on a certain scale. It is desirable that all the units are regular triangles of the same size. As a matter of fact, it is required to estimate temperature at apexes of regular triangles based on available temperature at actual stations. By the way, many methods to estimate a value at a certain point from observed values at neighbouring points have been proposed. Although some of them have been compared one another (Braile, 1978), it is indistinct which method is proper. So the author selected seventy-eight stations out of available stations as seen in Figure 2, considering that distance between neighbouring two stations became almost invariable. These selected stations were regarded as apexes of regular triangles and temperature observed at each station was used in the identification of units.

The spatial representativeness of temperature in mountainous regions is thought to be much smaller than that on the flat owing to topographical effect. So division of the temperature fields in mountainous regions is thought to be qualitatively different from that on the flat. When a certain unit in mountainous regions is identified as "homogeneous area", it is clear that the three stations of this unit have equal population mean, but it is dangerous to assert that population mean is equal at all places in the unit. When environment of stations in a "homogeneous area" is much different from that at the inside of the "homogeneous area", it is dangerous to assert that population means are equal at all places in that "homogeneous area". Such danger may also hold true in the case of "homogeneous area" by the seaside. One of such cases may be a "homogeneous area" appearing at the southernmost end of the Boso Peninsula in the southeast of the plain (cf. Figure 3).

A certain unit is identified as "homogeneous area", when three stations in this unit have equal mean. So it cannot be affirmed that all the stations in a lump of "homogeneous areas" have equal mean. Through testing difference of means not at specific pairs but at all the pairs of the stations, it can be ascertained whether all the stations in a lump of "homogeneous areas" have equal mean or not. By the way, lumps of "homogeneous areas" each of which has equal mean at all the stations may suggest both dimensions and regional difference of the spatial representativeness of temperature.

Perceivable climatic phenomena may depend upon distance between stations in the triangular network. By the way, as mentioned by Shitara (1969) and others, it might be almost impossible to uniformly divide all the climatic phenomena according to space-time scale like the division of meteorological phenomena by Orlanski (1975). Therefore it is desirable that distance between stations in the triangular network is set to perceive demanded climatic phenomena, referring to spatial dimensions of many climatic phenomena summarized by Yoshino (1975) and others. In the network of this investigation, distance between neighbouring stations is about 20–30 km. So areas where stations have equal mean have extent of more than 20–30 km. This extent corresponds to those of mesoclimate according to Yoshino (1961, 1975).

3. A Consideration on Factors Causing Regional Difference in Minimum Temperature Field of the Northern Part of the Plain

Introduction

As both the southern and the eastern parts of the plain border on the Pacific Ocean, maritime influence, which complicates explaining the causes leading the regional difference, on the temperature fields may be exerted on both parts, particularly on the southern part of the plain. So mechanism causing the regional difference in the field of the northern part of the plain where maritime influence may be not so strong is considered in this chapter.

The regional difference in the field of the northern part of the plain distinctly appears under the winter monsoon type and the migratory high type (Figure 5). So it might be better to handle the case under the winter monsoon type or the migratory high type. The migratory high type appears with average relative occurrence frequency of only 22%, on the contrary the winter monsoon type predominantly appears with the high frequency of 41%. Therefore, the winter monsoon type is regarded as a typical pressure pattern in winter season.

In chapter 2, regional difference in the temperature fields was revealed under the three items of the conditions of pressure patterns. It was found that peculiar regional difference appears in respective fields of minimum temperature and range of temperature. Comparing Figure 3 with Figure 4, regional difference in the field of range of temperature is very similar to that in the case of minimum temperature. In the field of maximum temperature, there appears no distinct regional difference. Therefore causes in the case of range of temperature may be obtained in consequence of explaining causes in the case of minimum temperature. The regional difference in the field of minimum temperature appearing in general around the time of sunrise is thought to be much similar to that in night temperature field. In fact, the relation between night temperature at Maebashi and at Utsunomiya (Figure 6) is the same that between minimum temperature shown in the previous chapter. Hereafter causes leading the regional difference in minimum temperature field of the northern part of the plain are fathomed based on data of night temperature and wind under the winter monsoon type.

As to causes of the regional difference in the Kanto Plains, Kayane (1963) examined the correspondence of strengthening of night surface wind with rising of night surface temperature, and suggested that night ground inversion layer was to some extent destroyed by forced convection caused by strong wind, and consequently air parcels of high temperature descended from upper air layer toward the ground to raise night surface temperature. Similar findings were reported by Young (1923) who examined a region of the southern California similar to the Kanto Plains in dimensions. By the way, Frankenberger (1955) found that austausch coefficient at night is in proportion to night wind speed. In addition, it has already been confirmed that night temperature in planetary boundary layer approaches still more neutral condition as night wind becomes stronger, and consequently night surface temperature rises (McAdie, 1912; Best, 1935; Siegel, 1936; Johnson & Heywood, 1938). The relation between night surface temperature and night surface wind was referred to also in the investigation of Young (1923). Investigating winter surface air streams of the Kanto Plains based on data observed at 09 JST, Kawamura (1966) found that strong north-

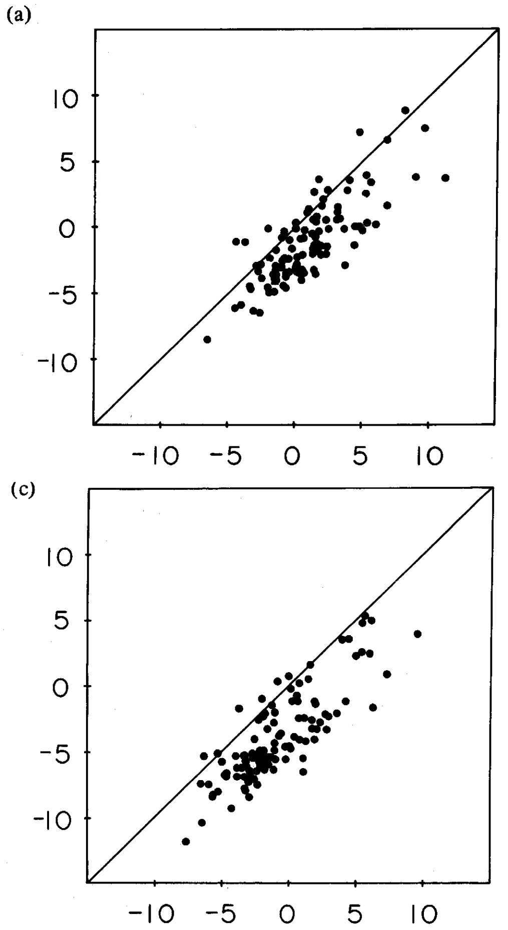


Fig. 6 Temperature (°C) at Maebashi (abscissa) and Utsunomiya (ordinate) under the winter monsoon type for the three winters
(a) at 00 JST (b) at 03 JST (c) at 06 JST

westerly wind blew over Tone region and on the contrary calm conditions were predominant over NE region, and found that an area where northwesterly wind blew corresponded to an area of high minimum temperature. Furthermore he suggested, as Geiger (1966) commented on Young (1923), that higher night temperature of the northwesterly wind as well as forced convection might be one of causes leading the regional difference in the Kanto Plains.

Kawamura (1966) ascertained air streams at 09 JST. However, to reveal the relation between night temperature and wind, it is necessary to ascertain actual night air streams. Among stations in the northern part of the plain, every three hourly observations of surface temperature and wind are available only at Utsunomiya (120 m a.s.l.), Maebashi (112 m a.s.l.) and Kumagaya (30 m a.s.l.). The station of Utsunomiya is in NE region and the stations of Maebashi and Kumagaya are in Tone region. At first night average wind speed (W) of a certain day is calculated by the following equation using an actual data at respective stations of Utsunomiya, Maebashi and Kumagaya;

$$W = (W_0 + 2W_3 + W_6)/4$$

where W_0, W_3 and W_6 are wind speed (m/sec) at 00, 03 and 06 JST, respectively. Then the average wind speed (W) is transformed into the Beaufort wind scale, and this transformed wind force is hereafter called average wind force. Occurrence frequencies of the average wind forces under the winter monsoon type are shown in Table 1. It is necessary to examine whether these average wind forces express actual wind forces at night. Actual data of wind speed at each time of 00, 03 and 06 JST are sorted according to the Beaufort scale of the average wind forces. From these sorted data of wind speed, interval estimates for mean wind speed at each time are calculated at the confidence level of 95%. And then wind speeds at both the ends of these interval estimates are transformed into the Beaufort wind scales. As a result, wind speeds at both the ends of a certain interval estimate were transformed into the same scale and moreover this scale was equal to that of average wind force. Therefore, the average wind forces are considered to express actual conditions of night wind forces.

At other stations, daily maximum and minimum temperature and surface wind are observed once a day, at 09 JST. So it is necessary to estimate occurrence frequencies of the average wind forces under the winter monsoon type to ascertain spatial pattern of the average wind forces at these stations. Here the author assumed that mutual relation based on wind at 09 JST holds true in the case of night wind. Mutual relation between the Beaufort wind scales of observed wind at 09 JST is obtained at every pair of stations, that is, one of the abovementioned three stations and one of the other stations, which is selected referring to the air stream system defined by Kawamura (1966). Frequencies of the average wind forces at the latter stations are estimated from both the mutual relation and the frequencies shown in Table 1.

From the actual frequencies of the average wind forces at the three stations of Utsunomiya, Maebashi and Kumagaya and the estimated frequencies at the other stations, it was clear that under the winter monsoon type, strong wind is liable to blow over Tone region and on the contrary, calm or breeze conditions are predominant in NE region. Furthermore it was clear that northwesterly wind predominantly blows over Tone region at night.

The abovementioned estimation revealed that estimated state of surface wind at night in the northern part of the plain was extremely similar to that at 09 JST investigated by Kawamura (1966).

Though Tone region where northwesterly wind blows at night nearly corresponds to an area of strong wind, it is impossible to determine whether temperature of the northwesterly wind is originally high and/or raised to the high level by forced convection. Therefore thermal characteristics of this northwesterly wind are investigated in the following section.

Table 1 Distributions of average wind forces under the winter monsoon type for the three winters

	AVERAGE WIND FORCE						
	0	1	2	3	4	5	6
Utsunomiya	1	38	69	2	–	–	–
Maebashi	–	3	29	64	10	3	1
Kumagaya	1	26	44	30	9	–	–

The Thermal Characteristics of NW Wind Airmass

Even if the amounts of heat in air columns of airmasses are the same, vertical profiles of temperature in these airmasses may be different each other according to different strength of forced convection, and consequently each airmass may have its own surface temperature. On the contrary when the amount of heat is different in different airmasses, there is every probability of the same surface temperature in the airmasses. Therefore thermal characteristics of an airmass cannot be grasped through an investigation of only surface temperature. Observation of upper part of an airmass is absolutely necessary to grasp thermal characteristics of the airmass. So night observation in planetary boundary layer is necessary to examine thermal characteristics of both the northwesterly wind airmass and the airmass occupying NE region. There is only a specially programed observation by Japan Meteorological Agency which was made in the Kanto Plains (Japan Meteorological Agency, 1977). Though routinized observation of planetary boundary layer is made at Tateno Aerological Observatory in the Kanto Plains, its location is out of both Tone and NE regions. In the specially programed observation vertical profile of temperature was observed at Kami-

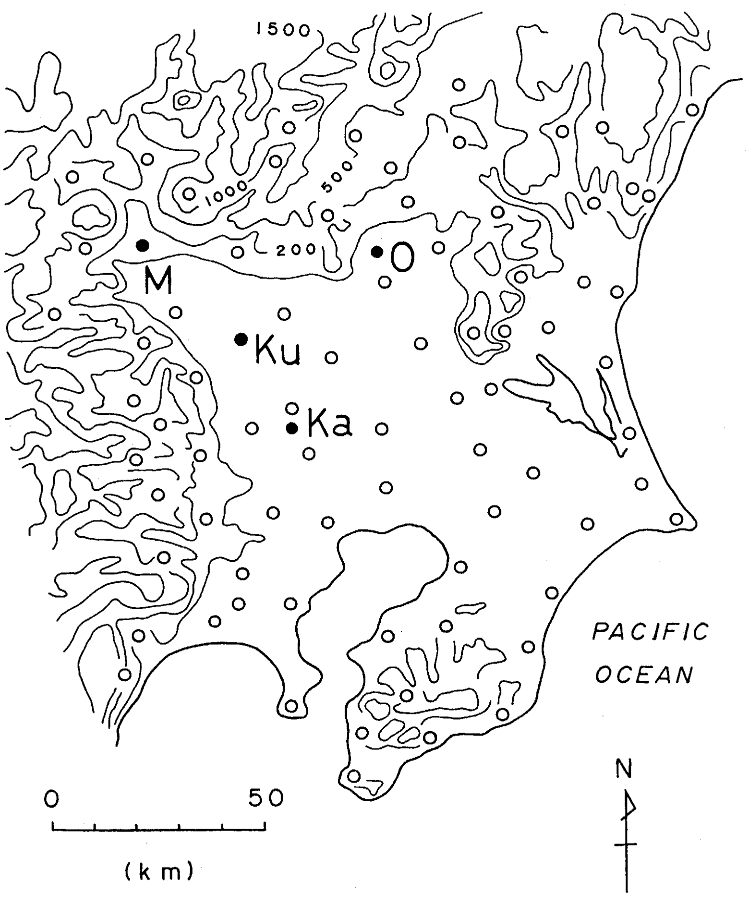


Fig. 7 Locations of Maebashi (M), Kumagaya (Ku), Kamifukuoka (Ka) and Oyama (O)

fukuoka (35 m a.s.l.) and Oyama (53 m a.s.l.), and wind speed and direction were vertically observed at Maebashi, Kumagaya and Kamifukuoka in the northern part of the plain. Only the station of Oyama is in NE region and the other three stations are in and around Tone region (Figure 7). In this section, the thermal characteristics are examined by analyzing the data of this specially programed observation.

The specially programed observation was made for twenty-eight days in all; from 25 November to 1 December 1974, from 1 August to 7 August 1975, from 10 December to 16 December 1975 and from 3 March to 9 March 1976. Among these, the author adopted a time span from 00 to 03 JST of 7 March 1976, because night surface wind and surface pressure pattern were similar to those under the winter monsoon type.

Though the station of Kamifukuoka is statistically out of Tone region of high minimum temperature, the vertical distribution of wind at the stations of Maebashi, Kumagaya and Kamifukuoka in the time span from 00 to 03 JST (Figure 8) showed that north-westerly wind with thickness of several hundred meters blew over an area from Maebashi to Kamifukuoka. So thermal characteristics of an airmass at Kamifukuoka in the time span are considered to be the same as those in Tone region. Hereafter the author analyzes the thermal characteristics at Kamifukuoka. On the one hand, NE region including the station

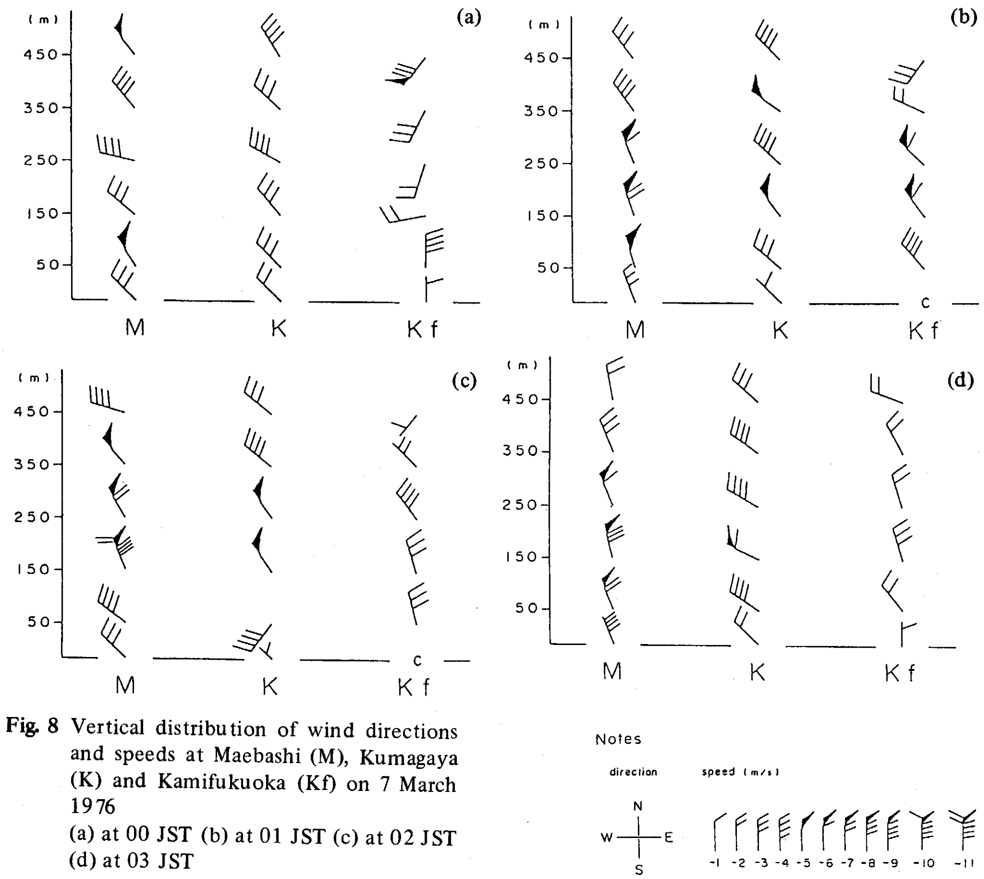


Fig. 8 Vertical distribution of wind directions and speeds at Maebashi (M), Kumagaya (K) and Kamifukuoka (Kf) on 7 March 1976
(a) at 00 JST (b) at 01 JST (c) at 02 JST
(d) at 03 JST

of Oyama was in the time span under nearly calm condition. Surface wind in NE region was nearly calm under the winter monsoon type. The condition of planetary boundary layer in NE region in the time span is regarded as one of the conditions under the winter monsoon type.

Vertical profiles of temperature at stations of Kamifukuoka and Oyama were observed around 00 and 03 JST during the time span and shown in Figure 9. It was found from this figure that ground inversion layers were developed up to about three hundred meters above the ground at the stations. In these layers, temperature at the same height was always higher at Kamifukuoka than at Oyama, and temperature at the stations fell with time. Temperature at 00 JST at Kamifukuoka was higher than at Oyama by 0.4°C on the average. At 03 JST temperature at Kamifukuoka was still higher than at Oyama by 1.4°C on the average. The decrease of temperature for three hours is 2.6°C and 1.6°C on the average at Oyama and Kamifukuoka, respectively.

In conclusion, it was found that the northwesterly wind airmass had high temperature at every height as compared with the airmass over NE region. These results support the the foregoing suggestion of Kawamura (1966).

Discussion and Conclusion

As mentioned before, Kayane (1963) suggested that forced convection accompanied with strong surface wind causes high minimum temperature. So influence of forced convection on night surface temperature is discussed under the winter monsoon type. Changes in night surface wind speed can be considered to relate with changes in strength of night forced convection and in night surface temperature. This is consistent with the results of Frankenberger (1955) and agreed with the suggestion of Kayane (1963). On the one hand, the planetary boundary layer in the northern part of the plain is inclined to be vertically

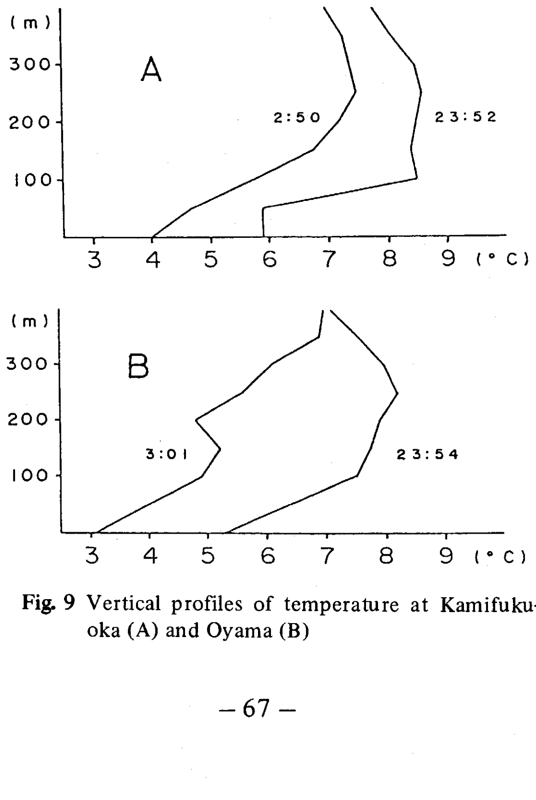


Fig. 9 Vertical profiles of temperature at Kamifukuoka (A) and Oyama (B)

stable at night (Japan Meteorological Agency, 1977). The ratio (KH/Km) of the thermal diffusivity (KH) to the momentum diffusivity (Km) in planetary boundary layers under vertically stable conditions varies in compliance with the stability (Ellison & Turner, 1960; Record & Cramer, 1966; Arya & Plate, 1969; Arya, 1972; Pruitt et al., 1973; Kondo et al., 1978). Correlation between amounts of hourly changes in both surface temperature and surface wind speed under the winter monsoon type for the three winters is examined using data observed at night from 00 to 05 JST at the station of Maebashi where hourly observation is made. Correlation coefficient was 0.46 and significant at the level of 1%. This small value may reflect the fluctuation of both the stability and the ratio (KH/Km). Regional difference in surface wind, that is, strength of forced convection is certainly one of the causes leading regional difference in minimum temperature field.

Analysis mentioned before showed that temperature is higher at every height in the airmass over Tone region than over NE region. The author concluded that regional difference both in strength of forced convection and in thermal characteristics of airmasses can be given as the causes leading regional difference in night surface temperature and minimum temperature fields.

Hereafter the mechanism by which warm wind blows over Tone region is examined. As mentioned before, strong northwesterly wind blows over Tone region while nearly calm condition is predominant in NE region. Spatial distribution of night surface wind in and around Tone region indicates that calm or breeze condition is predominant at stations on the windward side while strong northwesterly wind blows on the leeward side of Maebashi. Momentum is transferred from the upper layer not to the windward but to the leeward of Maebashi, and consequently discontinuity of surface wind appears near Maebashi and momentum is transferred from the upper layer to Tone region.

Minimum temperature is higher on the leeward side of Maebashi than on the windward side. This distribution of minimum temperature might be caused only by spatial difference in surface wind speed, in a word, spatial difference in strength of forced convection. By the way, NE region and the windward side of Maebashi have nearly equal altitudes and minimum temperature, and calm or breeze conditions are predominant in these two regions. Furthermore, these two regions have no distinct difference in the terrestrial conditions like vegetation which regulate to a large extent heat budget at the ground. So airmasses over NE region and the windward side of Maebashi are regarded to have nearly equal thermal characteristics. On the one hand, it was found that temperature of airmass of strong northwesterly wind is higher than that over NE region. So temperature of strong northwesterly wind airmass can be considered to be higher than that over the windward of Maebashi. No clear discontinuity of the terrestrial conditions in the vicinity of Maebashi indicates that sensible heat as well as momentum is transferred from the upper layer not to the windward but to the leeward of Maebashi.

Defant (1952) stated that the fall wind is generally gusty around the mouth of a valley. Summarizing some investigations on the fall wind, Arakawa (1975) also stated that the fall wind tends to be gusty around the mouth of a valley at the leeward foot of mountains. Distribution of night surface wind shows that wind blows hard particularly around the station of Maebashi. The mouth of a valley extending north and south is to the north of Maebashi. These topographical and surface wind conditions suggest the existence of the fall wind on the leeward of Maebashi. And as a consequence, momentum and sensible heat are thought to be transferred from the upper layer toward the lower layer accompanied with the fall wind, and this fall wind airmass also seems to raise its temperature through the dry adiabatic process.

The amount of changes in temperature was larger in the airmass over NE region than that over Tone region. Nakagawa (1978) estimated, using experimental formulae, average long wave radiation budgets of Januaries from 1941 to 1970 and obtained nearly equal averages of −155 ly/day at Maebashi and −146 ly/day at Utsunomiya. According to Yoshino and Kai (1974), relative occurrence frequency of the winter monsoon type in January is a large value of 46.5% in the period from 1941 to 1970. So the author considers that the foregoing average long wave radiation budgets at the stations may be those under the winter monsoon type, and that the airmasses over Tone and NE regions lose almost the same amount of heat at night. However this consideration cannot explain the difference of the amounts of temperature changes.

Under the winter monsoon type, averages of surface wind speed at 00, 03 and 06 JST are 1.8 m/sec at Utsunomiya and 4.2 m/sec at Maebashi. The airmass over NE region tends to stagnate, on the other hand there is an incessant change in airmass over Tone region. The airmass trespassing on Tone region is considered to have a feature of small fall of temperature with time as compared with the airmass stagnating over NE region. The range of diurnal change in temperature tends to be narrower as level in the air becomes higher (for example, Yoshino, 1975). This tendency may hold true in the case of the change for several hours. So the author concluded that the airmass trespassing on Tone region is an airmass descending from the upper layer.

Manley (1945), Larsson (1954), Gerbier and Berenger (1961), Vergeiner and Lilly (1970), Starr and Browning (1972), Yoshimura et al. (1974) and others investigated lee waves. They reported that these lee waves had wavelengths from 5 to 30 km. Therefore, it does not seem probable that the fall wind descends directly over the whole of Tone region. Considering the distribution of temperature and wind in the vicinity of Maebashi, the fall wind must descend directly around Maebashi.

The results are summarized as follows: The fall wind blows over Tone region whereas nearly calm condition is predominant over NE region. Night temperature in Tone region is high through forced convection and heating due to the dry adiabatic process accompanied with the fall wind, as compared with that in NE region. Diurnal range of temperature in the upper air is narrow as compared with that in the lower air. This tendency is to some extent maintained in the descending airmass, as a consequence, which makes the regional difference in the field more distinct. An area where the upper airmass descends is thought to be an area of high temperature compared with its surroundings. Therefore, when an area occupied by descending air frequently shifts its location to and fro, extent of an area with the same mean temperature will become large. The fact that under the trough type a large lump of "homogeneous areas" appears in the middle of the plain is probably related with the changeableness of air stream system due to rapid movements and unfixed courses of cyclones. Under the winter monsoon type relativelly high minimum temperature appears in a limited area. This is because the fall wind descends in a limited area under the winter monsoon type. Mountain ranges are to the north and the west of the plain and a valley opens its mouth to the north of Maebashi. Under these large and small scale topographical conditions, a particular pressure pattern of the winter monsoon type makes an airmass which has crossed over the northern mountains descend over the limited area of Tone region and makes other airmass stagnate over NE region. So it is clear that both the topographical and the pressure conditions must be fundamental causes leading the peculiar regional difference in minimum temperature field.

4. Concluding Remarks

At first population means were estimated based on samples drawn under the selected sampling conditions and the division of the winter surface temperature fields was made in terms of estimated population means. Peculiar regional difference was confirmed to appear in minimum temperature field of the northern part of the Kanto Plains, particularly under the winter monsoon type distinctly. An area with high minimum temperature compared with its surroundings appears in the northwestern part of the plain "Tone region", on the other hand in the northeastern part "NE region" appears an area with low minimum temperature compared with the surroundings. Causes leading this peculiar regional difference were also examined. And the author found out that the difference might be caused by the following mechanism: In NE region air stagnates and consequently radiation cooling is vigorous at night. Minimum temperature in this region is consequently low compared with the surroundings. On the one hand, in the northwestern part of the plain, air crossing over the northern mountains descends over Tone region and becomes high in temperature at night through the dry adiabatic process, compared with its surrounding air. Moreover, this descending air brings momentum toward the ground and makes forced convection so vigorous that warm upper air in the inversion layer descends to cool lower layer at night. It was concluded that both the differences in the thermal characteristics of air and in strength of forced convection lead the regional difference in minimum temperature field of the northern part of the plain.

The division of the temperature fields made by means of the statistical inference should be almost invariable, while the division made by mere sample statistics is variable. Invariable aspects of climatic phenomena are supremely important in climatology.

The examination of causes leading the regional difference was limited to the northern part of the plain. Complicated factors involving urban climate of Tokyo and maritime influence may contribute to the regional difference in the southern part of the plain. Examination of these factors will be particularly important to explain the regional difference in the southern part of the plain.

The distribution of "homogeneous areas" in minimum temperature field under the winter monsoon type was similar to that under the migratory high type. Assuming that there exists no fall wind crossing over the northern mountains under the migratory high type, forced convection might be a main cause leading the regional difference. By studying further the effect of forced convection on the regional difference under the migratory high type, the effect of dry adiabatic heating accompanied with the fall wind might be in the result quantitatively estimated. Anyhow, consideration of the causes based on more quantitative data will be necessary. It will be also necessary to reinforce the explanation of causes with simulation.

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