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# Regional Characteristics of Heavy Rainfalls in Hokkaido, Japan

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**Abstract**

The distributions of annual rainfall amounts in Hokkaido, the northern island of Japan, are characterized by high rainfall amounts around the southeast slopes of the Orofure mountain range and the Hidaka mountain range, the southwest area of Oshima Peninsula and the northeast area of Shiretoko Peninsula. Heavy rainfalls ($\geq$90 mm/day) occur frequently around the southeast slopes of the Orofure mountain range and Hidaka mountain range. In these areas it is supposed that the occurrence frequency of heavy rainfalls contributes to the annual rainfall amounts.

Based on the results from principal component analysis, the distributions of rainfall amount on heavy rainfall days are characterized by cases; rainfalls of all over Hokkaido, only in a limited area, a seesaw pattern of east and west, and a seesaw pattern of south and north. It is shown that each pattern relates to the various courses of meteorological disturbances passing around Hokkaido.

## 1. Introduction

Generally speaking, rainfall amounts in Hokkaido are less than those in southwestern Japan, but heavy rainfalls occur in some areas and a lot of rainfall damage has been caused in the past. Recently, rainfall damage has been transformed and has increased owing to changes in human activity. For example, as man begins to live in developed areas near hillsides, he incurs damage from landslides caused by local heavy rainfalls. It is assumed that this

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will increase in the future. In order to lessen and possibly prevent damage caused by heavy rainfall, the prediction of local heavy rainfalls would be of great use. But, it is difficult to understand and predict local heavy rainfalls, because they have characteristics which are concentrated in a short time and in a narrow area.

For accurate predictions, the actual state and mechanism of local heavy rainfalls must be clearly known. Based on observations by radar, rain gauges and so on, heavy rainfalls in Hakkaido have been investigated by the method of case study (e.g. Harimaya and Tobizuka, 1988). But, a few researchers have studied the statistical characteristics of heavy rainfalls all over Hokkaido (e.g. Takeda and Kikuchi, 1978). Therefore, it is important to study the regional characteristics of heavy rainfalls in Hokkaido by using a detailed map of horizontal distribution of rainfall amounts and the method of principal component analysis. Akiyama (1981a, 1981b) and Tachibana (1994) studied snowfall by principal component analysis. Of the two, Tachibana (1994) studied snowfall in Hokkaido. Only a few researchers (e.g. Yamazaki and Kinami, 1977) have applied principal component analysis to rainfall patterns.

In the present paper, the detailed map is described on the horizontal distribution of rainfall amounts using data by AMeDAS (Automated Meteorological Data Acquisition System), and the characteristics of rainfall patterns are represented by principal component analysis. Next, the meteorological elements causing them are inferred by synoptic analysis. The aim of the present paper is to get the basic facts on prediction methods for heavy rainfalls by synthesizing the above-mentioned results.

## 2. Data and analytical methods

The analyses in this study were carried out using AMeDAS data in the periods from April to October for the past 10 years from 1980 to 1989, as the snowfall period is from November to March in Hokkaido. The data used in this study were taken from 180 AMeDAS observation points, which had few deficiencies in observation data, out of a total of 227 AMeDAS observation points in Hokkaido. The data used for the principal component analysis were daily rainfall amounts on those heavy rainfall days when rainfall amounts rose above 90 mm/day at any one point. This is because rainfall damage in Hokkaido occurs when rainfall is over 90 mm/day (Takeda and Kikuchi, 1978).

The utility of principal component analysis is that the principal portion of a vast data field is able to be described by a few factors (e.g. Barnett, 1977 ;

Maki and Harimaya, 1984). Mathematical descriptions of principal component analysis are given in many text books.

## 3. Results

### *3.1 Annual mean rainfall amount and frequency of heavy rainfall*

Figure 1 shows the distribution of annual mean rainfall amount from April to October for the past 10 years from 1980 to 1989. The annual mean rainfall amount was 695 mm, as an average from all over Hokkaido. From this figure, it is seen that areas of high rainfall amounts (over 1,000 mm) exist around the southeast slopes of the Orofure mountain range and the Hidaka mountain range, the southwest area of Oshima Peninsula and the northeast area of Shiretoko Peninsula. These area have geographical characteristics which effectively transform warm humid air to rainfall due to the topographical updraft and

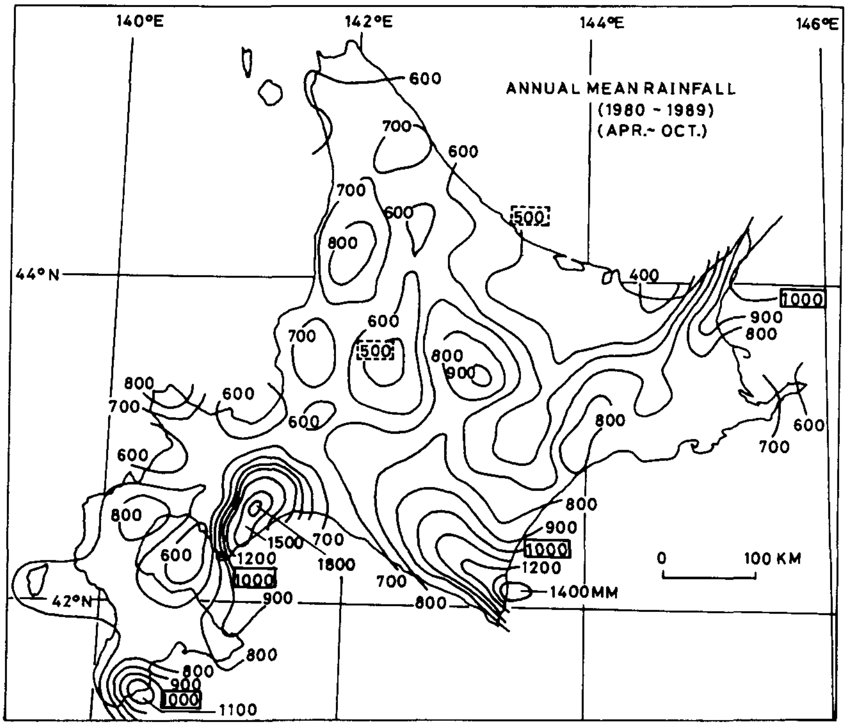


Fig. 1. Distribution of the annual mean rainfall amount in the warm period (April to October) from 1980 to 1989.

convergence effect of the coastal area. These characteristics have been shown by the analytical results of data from 1965 to 1974 by Harimaya et al. (1981). On the other hand, the Abashiri district is an area which has only little rainfall.

Figure 2 shows the frequency of heavy rainfalls which rise above 90 mm/day. Solid circles represent the number of occurrence frequency of heavy rainfalls by size. Areas of high occurrence frequency exist in the southeast slopes of the Orofure mountain range and the Hidaka mountain range. They are the same areas as the areas of high rainfall amounts shown by Fig. 1. That is to say, it is supposed that there is a high occurrence frequency of heavy rainfalls in the two areas and it follows that this increases the annual rainfall amounts.

The smallest solid circle represents a heavy rainfall occurrence frequency of 6-10 times over 90 mm/day. It is seen that this symbol is concentrated in the coastal area of eastern Hokkaido and the Ishikari Plain. It is supposed that heavy rainfall happens in the coastal area of eastern Hokkaido owing to the inflow of warm humid air. But, there are not high annual rainfall amounts in the Ishikari Plain, while there is a high occurrence frequency of heavy rainfall. This finding is interesting, and is analyzed in the next section.

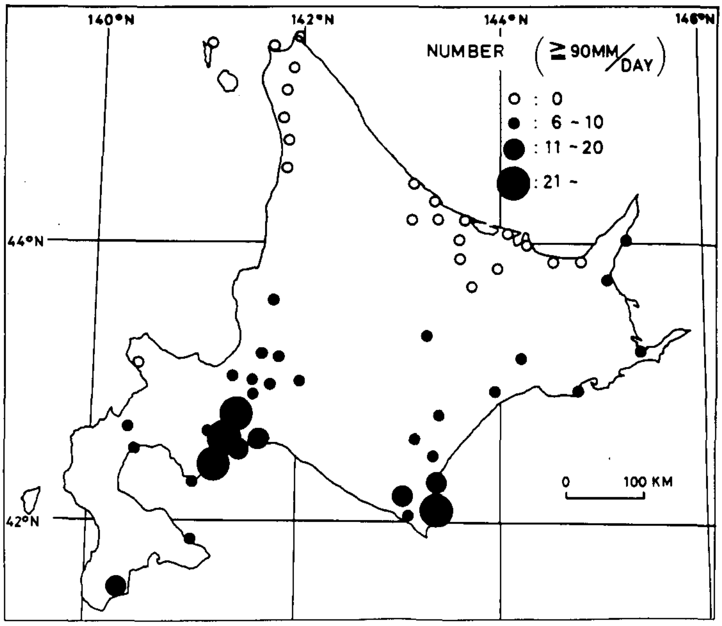


Fig. 2. Frequency of heavy rainfall (≧90 mm/day) from 1980 to 1989.

On the other hand, the open circle symbols show the points where heavy rainfalls over 90 mm/day did not occur during the analyzed period and there were 22 such points over Hokkaido. It is seen that they are concentrated in the Abashiri district and northern Hokkaido. This area, and especially Abashiri district, corresponds to the areas which have only low annual rainfall amounts. It can be seen in Figs. 1 and 2 that southern Hokkaido has a high occurrence frequency of heavy rainfalls and high annual rainfall amounts, while northern Hokkaido has a low occurrence frequency of heavy rainfalls and low annual rainfall amounts.

### 3.2 *Characteristics regarding spatial distribution of rainfall amounts on heavy rainfall days*

In order to examine the characteristics regarding spatial distribution of rainfall amounts on heavy rainfall days in Hokkaido, principal component analysis was applied to the data of daily rainfall amounts at AMeDAS points. Table 1 shows the eigenvalue, proportion and accumulated proportion from the first principal component to the tenth principal component. Here, it should be noted that the proportion is more than about 10% from the first principal component to the third principal component. As the accumulated proportion is 61.3% up to the third principal component, we can understand about 60% of the characteristics regarding the spatial distribution of rainfall amounts on heavy rainfall days in Hokkaido if we can understand the facts from the first principal

Table 1. Eigenvalue, proportion and accumulated proportion from the first principal component to the tenth principal component.

| Principal component $Z_j$ | Eigenvalue | Proportion (%) | Accumulated proportion (%) |
|---|---|---|---|
| $Z_1$ | 68.7 | 38.2 | 38.2 |
| $Z_2$ | 24.1 | 13.4 | 51.6 |
| $Z_3$ | 17.4 | 9.7 | 61.3 |
| $Z_4$ | 10.8 | 6.0 | 67.3 |
| $Z_5$ | 7.9 | 4.4 | 71.7 |
| $Z_6$ | 4.9 | 2.7 | 74.4 |
| $Z_7$ | 4.6 | 2.5 | 76.9 |
| $Z_8$ | 3.7 | 2.0 | 78.9 |
| $Z_9$ | 3.4 | 1.9 | 80.8 |
| $Z_{10}$ | 2.4 | 1.4 | 82.2 |

component to the third principal component.

First, it is shown in Fig. 3 how spatial distribution is represented regarding the eigenvector elements of the first principal component. It can be seen from the figure that all the eigenvector elements are positive values. The areas less than 0.05 indicated by dotted lines correspond to the areas of high annual rainfall amounts such as the southeast slopes of the Orofure mountain range and the Hidaka mountain range, the southwest area of Oshima Peninsula and the eastern area of Shiretoko Peninsula shown in Fig. 1. On the other hand, the area of the largest value is Ishikari district. But, the areas of low annual rainfall amounts do not always have high eigenvector elements, because areas of more than 0.07 cover the major part of Hokkaido. Therefore, it can not be considered to be able to represent the values of annual rainfall amounts from the first principal component.

Next, it is examined in detail what is to be represented by the first principal component. From Figs. 2 and 3 it seems that the areas less than 0.05 in

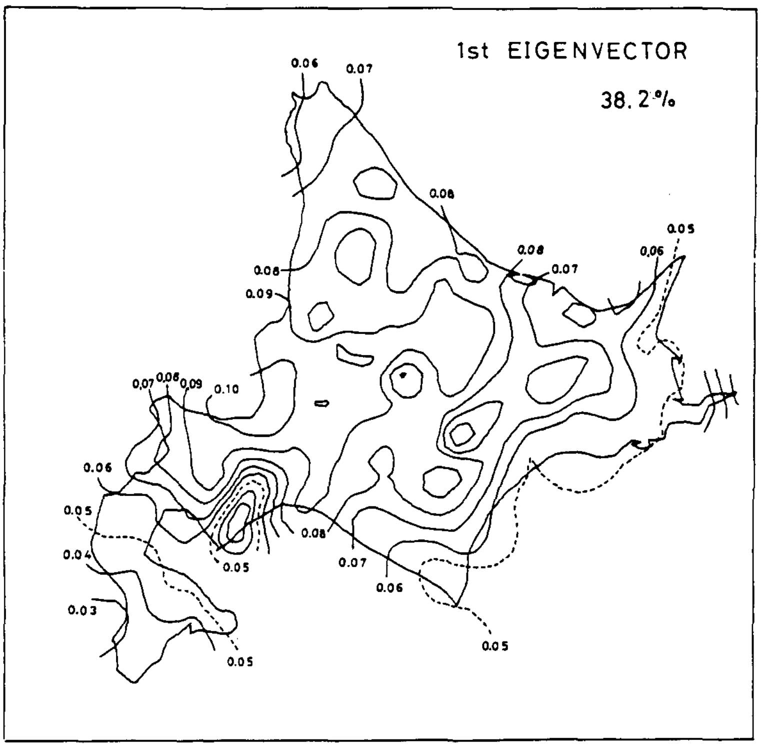


Fig. 3. Distribution of eigenvector elements of the first principal component.

eigenvector elements correspond to the areas of high occurrence frequency of heavy rainfalls. Therefore, it is assumed that high or low values of the eigenvector elements represent heavy rainfall all over Hokkaido, or rainfall in one region due to topographical effects.

In order to confirm this, three cases are selected from both the higher and lower scores of the first principal component, and Fig. 4 shows a comparison of both of these, based on rainfall distribution maps. The stippled areas and black areas show over 30 mm/day and over 90 mm/day, respectively. In the cases of the higher scores, the areas of high rainfall amounts cover a wide area. On the

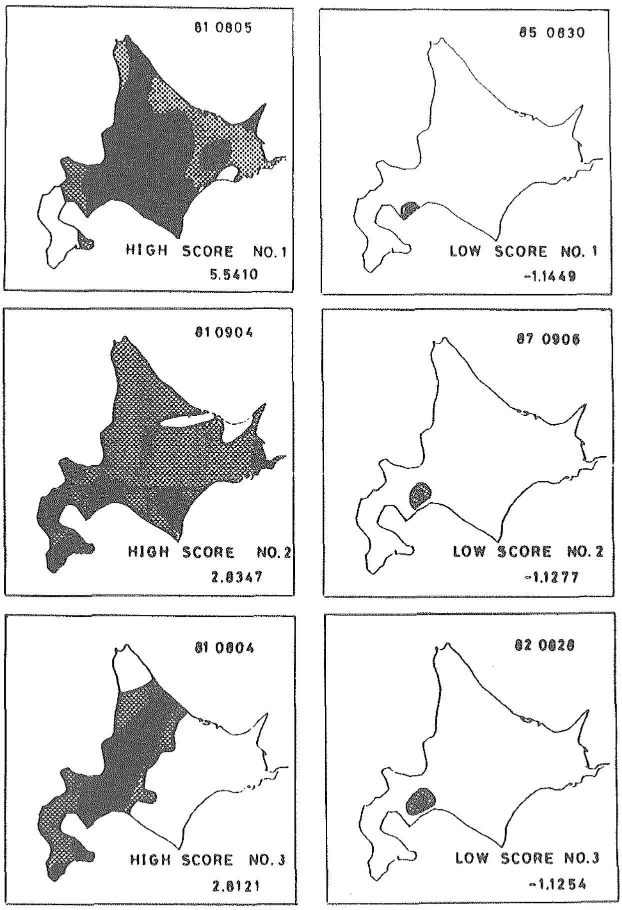


Fig. 4. Comparison of the distributions of daily rainfall amount between the cases of high score and lower score in the first principal component. The stippled areas and black areas show over 30 mm/day and over 90 mm/day, respectively.

other hand, in the cases of lower scores the areas are limited to special areas such as the southeastern slope of the Orofure mountains.

In order to examined the results in more detail, we have increased the number of examples, and shown the high-ranking values up to the ninth in Table 2 and low-ranking values up to the ninth in Table 3. Tables 2 and 3 show the daily mean rainfall amounts all over Hokkaido, the number of observation points observing over 90 mm/day and the number of observation points observing 0 mm/day in every case. It can be seen that the difference regarding the

Table 2. Characteristics of rainfall in the case of high-ranking values up to the ninth in the first principal component.

| Ranking | Date | Score | Mean rainfall amount (mm/day) | Number of stations (≧90 mm/day) | Number of stations (0 mm/day) |
|---|---|---|---|---|---|
| 1 | 810805 | 5.5410 | 145.8 | 89 | 0 |
| 2 | 810904 | 2.8347 | 98.2 | 39 | 0 |
| 3 | 810804 | 2.8121 | 86.3 | 48 | 7 |
| 4 | 810823 | 2.5811 | 94.4 | 44 | 0 |
| 5 | 890828 | 2.5706 | 89.1 | 29 | 0 |
| 6 | 860904 | 2.3439 | 80.4 | 29 | 0 |
| 7 | 850901 | 2.0835 | 80.5 | 31 | 4 |
| 8 | 820913 | 1.6381 | 71.7 | 6 | 0 |
| 9 | 880826 | 1.5190 | 62.4 | 12 | 0 |

Table 3. As in Table 2 except for low-ranking values up to the ninth in the first principal component.

| Ranking | Date | Score | Mean rainfall amount (mm/day) | Number of stations (≧90 mm/day) | Number of stations (0 mm/day) |
|---|---|---|---|---|---|
| 122 | 850830 | −1.1449 | 3.1 | 1 | 100 |
| 121 | 870906 | −1.1277 | 4.0 | 1 | 118 |
| 120 | 820828 | −1.1254 | 4.5 | 1 | 122 |
| 119 | 880731 | −1.0605 | 4.5 | 1 | 150 |
| 118 | 840914 | −1.0311 | 7.6 | 2 | 91 |
| 117 | 830624 | −1.0040 | 7.6 | 1 | 74 |
| 116 | 840918 | −0.9860 | 5.7 | 1 | 108 |
| 115 | 850930 | −0.9762 | 10.0 | 1 | 81 |
| 114 | 800829 | −0.9095 | 10.0 | 1 | 60 |

numbers of points over 90 mm/day and at 0 mm/day exists obviously between the days with higher scores and lower scores. That is to say, in the cases of higher scores, heavy rainfalls occur in a wide area, while in the cases of lower scores, they occur only in a limited area. Therefore, it can be seen from the above-mentioned results that the first principal component shows whether heavy rainfalls occur all over Hokkaido or whether they occur locally in a limited area.

The proportion of the second principal component is 13.4%. The elements of eigenvector are indicated in Fig. 5 in the form of distribution. It is characteristic that Hokkaido is divided into two areas so that the values are positive in eastern Hokkaido and negative in western Hokkaido. That is to say, it shows that heavy rainfalls do not occur in western Hokkaido when they are occurring in eastern Hokkaido, and the reverse is also true.

The proportion of the third principal component is 9.7%. The elements of eigenvector are shown in Fig. 6. It is characteristic that Hokkaido is divided

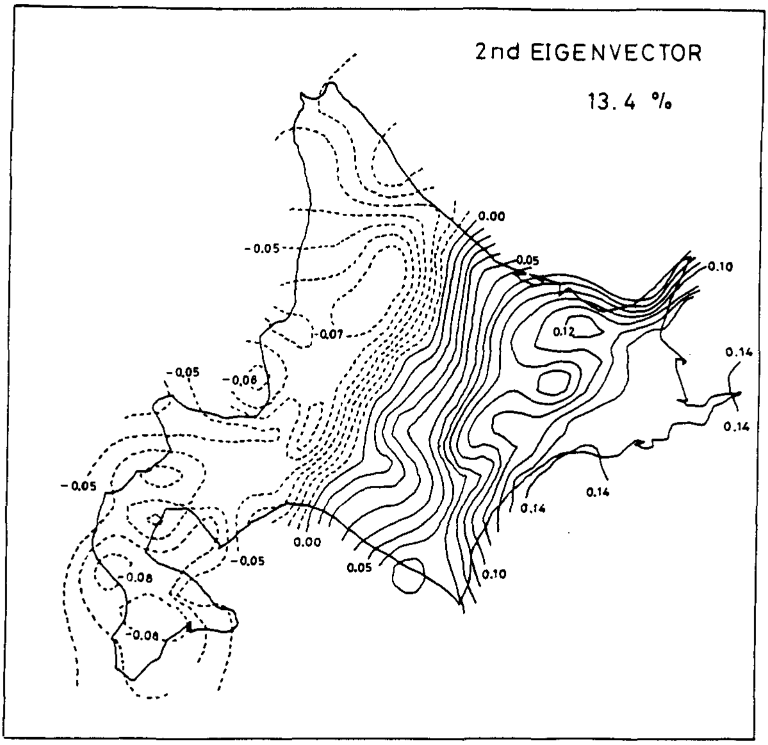


Fig. 5. As in Fig. 3 except for the second principal component.

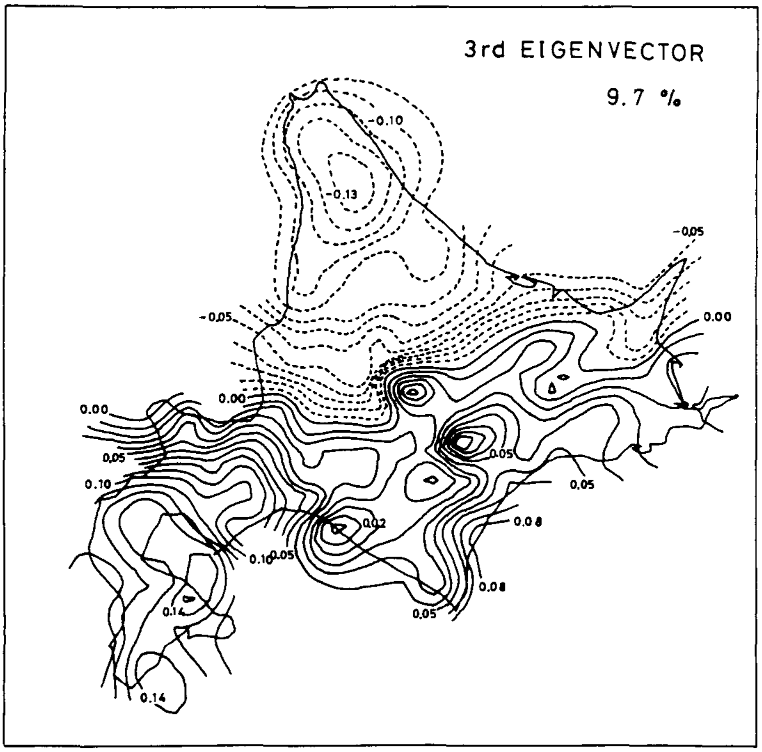


Fig. 6. As in Fig. 3 except for the third principal component.

into southern and northern areas. It shows that heavy rainfalls do not occur in northern Hokkaido when heavy rainfalls are occurring in southern Hokkaido, and the reverse is also true.

## 4. Discussion

In this chapter we examine how meteorological elements relate to the characteristics of distribution of rainfall amounts on heavy rainfall days. First, the occurrence number of heavy rainfall days in each month and the cause of its occurrence are examined and summarized in Table 4. Heavy rainfall days are concentrated in August and September. It is considered to be caused by the southward movement of the Akisame front. It is mainly caused by cyclones, typhoons, fronts and their combinations, while it is seldom caused by the unstable state of the atmosphere. That is to say, it can be seen that the occurrence of heavy rainfalls in Hokkaido is caused by meteorological distur-

Table 4. Occurrence numbers of heavy rainfall days in each month (top) and cause of its occurrence (bottom).

| Month | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. |
|---|---|---|---|---|---|---|---|
| Occurrence frequency of heavy rainfall day | 5 | 6 | 10 | 19 | 41 | 28 | 17 |

| Cause of occurrence | Cyclone | Typhoon | Front | Cyclone & typhoon | Front & typhoon | Front & cyclone | Unstable state of atmosphere |
|---|---|---|---|---|---|---|---|
| Frequency | 83 | 17 | 6 | 3 | 8 | 2 | 6 |

bance.

Therefore, analyses were carried out to connect the positions and courses of meteorological disturbance with the characteristics of distributions of rainfall amounts in the five cases of ; the first principal component, and positive value

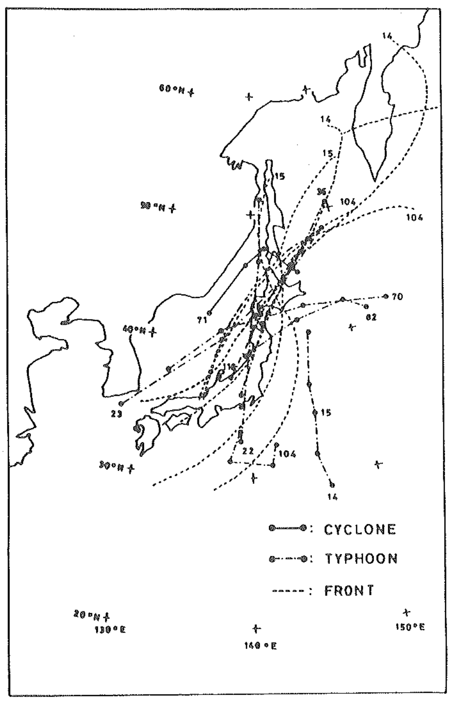


Fig. 7. Courses of cyclones and typhoons, and positions of fronts regarding the first principal component.

and negative value in the score of the second principal component, positive value and negative value in the score of the third principal component. To put it concretely, the positions and courses of meteorological disturbance were plotted on the map with regard to examples with higher scores in the five cases. Cyclones, typhoons (including the typhoons which transformed into extratropical cyclones) and fronts are shown by solid line, chained line and dotted line, respectively. The meteorological disturbances were tracked using surface weather maps at 09 and 21 JST. In the case of cyclones and typhoons, they were tracked using data including the weather maps at 21 JST of the day before a heavy rainfall day and at 09 JST of the day after a heavy rainfall day. In the case of fronts, their positions at 09 and 21 JST of heavy rainfall days are indicated on the weather maps.

Figure 7 shows the positions and courses of meteorological disturbance regarding the first principal component. This pattern presents a typical situa-

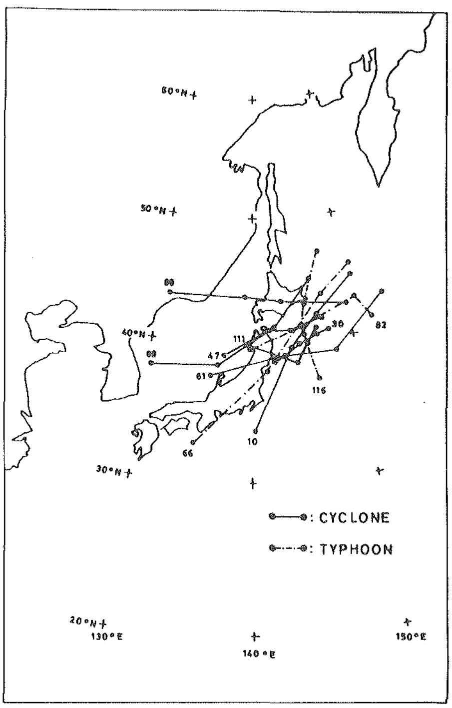


Fig. 8. As in Fig. 7 except for high-ranking scores up to the tenth in the second principal component.

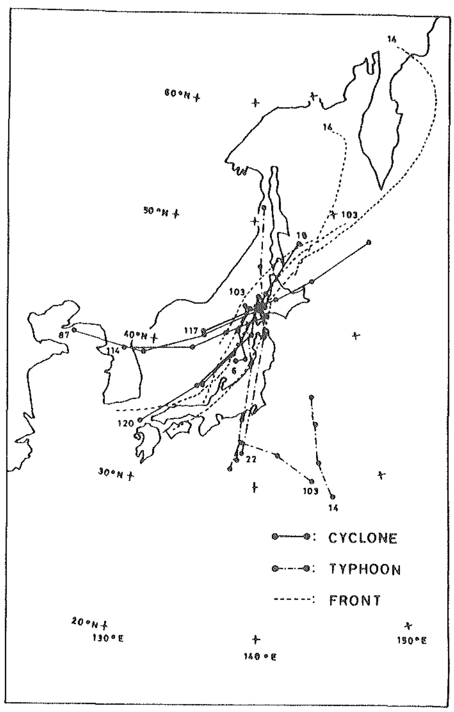


Fig. 9. As in Fig. 7 except for low-ranking scores up to the tenth in the second principal component.

tion where heavy rainfall covered all of Hokkaido. Such heavy rainfall is characterized by the landing of a typhoon or by the interaction between a typhoon and a front. Generally speaking, it is considered that heavy rainfalls covering all of Hokkaido during the past 10 years were related to the landing of typhoons, though the term typhoon also includes when a typhoon transforms into an extratropical cyclone.

In the case of the second principal component, high positive values in the element of eigenvector were seen in eastern Hokkaido, while high negative values in the element of eigenvector were seen in western Hokkaido. Therefore, in order to connect the analyzed results of principal component analysis with the distribution of rainfall amounts, the courses of meteorological disturbance and positions of front are plotted regarding high-ranking scores up to the tenth in Fig. 8, while they are plotted regarding low-ranking scores up to the tenth in Fig. 9. It can be seen from each figure that meteorological disturbances

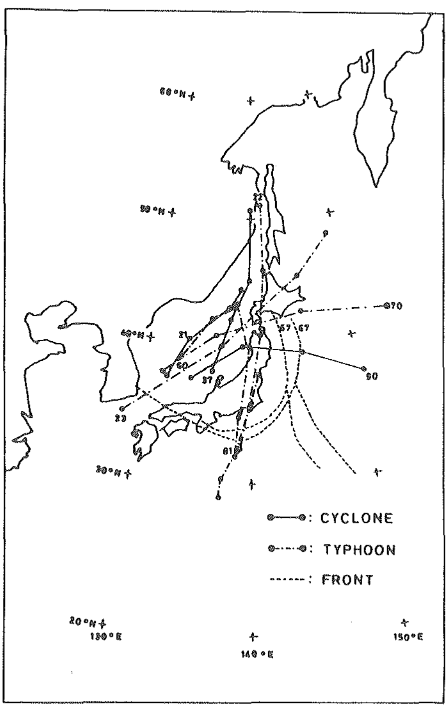


Fig. 10. As in Fig. 7 except for high-ranking scores up to the tenth in the third principal component.

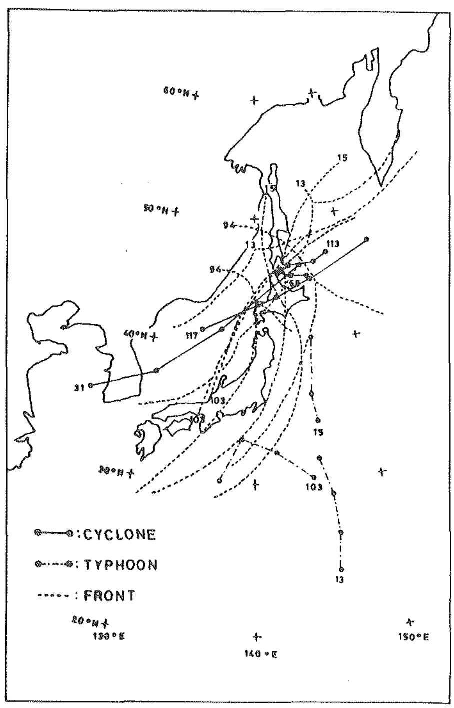


Fig. 11. As in Fig. 7 except for low-ranking scores up to the tenth in the third principal component.

pass through the sea to the east of Hokkaido when high positive values in the element of eigenvector are seen in eastern Hokkaido, and on the contrary, the reverse is also true. From this analysis, the fact that the distribution of rainfall amounts is divided into two areas can be explained by the courses of the meteorological disturbances.

In the case of the third principal component, high positive values in the element of eigenvector were seen in southern Hokkaido, while high negative values in the element of eigenvector were seen in northern Hokkaido. Therefore, the courses of the meteorological disturbances and the positions of fronts were plotted regarding high-ranking scores up to the tenth in Fig. 10, while they are plotted regarding low-ranking scores up to the tenth in Fig. 11 in the same manner as for the second principal component. From this analysis, the fact that the distribution of rainfall amounts is divided into two areas can be explained by the courses of the meteorological disturbances. From the second and third principal components, it can be seen that heavy rainfalls occur in only its half side of Hokkaido when meteorological disturbances pass through coastal areas.

## 5. Conclusions

In order to study the regional characteristics of heavy rainfall in Hokkaido, analyses were carried out using AMeDAS data. The analyses showed that areas of high rainfall amounts (over 1,000 mm) exist around the southeast slopes of the Orofure mountain range and the Hidaka mountain range, the southwest area of Oshima Peninsula and the northeast area of Shiretoko Peninsula. Areas of high occurrence frequency of heavy rainfalls ($\geqq 90$ mm/day) exist on the southeast slopes of the Orofure mountain range and the Hidaka mountain range and they are the same areas as the areas of high rainfall amounts. Therefore, it is assumed that there is a high occurrence frequency of heavy rainfall in the two areas and it follows that this increases the annual rainfall amounts.

Based on the results of principal component analysis applied to rainfall amounts on heavy rainfall days, the first principal component shows whether heavy rainfalls occur all over Hokkaido or whether they occur locally in limited areas. The second principal component shows whether heavy rainfalls occur in eastern Hokkaido or western Hokkaido. The third principal component shows whether heavy rainfalls occur in southern Hokkaido or northern Hokkaido. The results which connected the patterns of rainfall amounts with meteorological elements are as follows. Those heavy rainfalls which covered all of Hokkaido are related to the landing of a typhoon. Heavy rainfalls occur in only its half side of Hokkaido when meteorological disturbances pass through coastal areas. From the above results, it is considered that the spatial range of heavy rainfalls can be predicted if the course of meteorological disturbances can be predicted.

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