CROSS-ASSOCIATION OF DAILY WEATHER IN JAPAN

Takuzo HOHGETSU

Abstract Distributions of stations where daily weathers significantly correspond to those at respective specified stations are revealed. It is also revealed what kinds of daily weather restict the distributions. Then factors which bring weathers restricting the distributions are estimated.

1. Introduction

Despite the importance of weather, a complex of the climatic elements, to our society and individuals, it has not been well investigated compared with respective climatic elements, *i.e.*, temperature, precipitation, wind and others. It may come from the following reason. Data of weather are composed of nominal variables, and consequently method processing weather data is limited compared with method processing quantitative data.

Some weather divides in Japan were investigated by comparing monthly precipitation amounts or analysing confines of precipitation (Fukui, 1966; Suzuki, 1961; Takahashi, 1968; for instance). And some features of weather occurrence in Japan were also analysed in terms of entropy (Hoshino, 1970; for instance). However, it has not revealed whether occurrence of daily weathers at one point are closely associated with those at other points, *i.e.*, to what degree daily weathers at points correspond one another. No distribution of points where daily weathers are closely associated one another has been also revealed. In this paper the distribution will be investigated and some factors restricting the distribution will be also discussed.

2. Data and Method

Daily weather is specified by both precipitation amount and sunshine duration. The daily weather at all the stations in every season must be specified based on the same criteria. Referring to the sunrise and sunset times changing with season and places, sunshine duration and precipitation amount from 8 to 16 Japan Standard Time (JST) are taken in this investigation. These two elements from 8 to 16 JST, which are observed by Automated Meteorological Data Acquisition System (AMeDAS) of Japan

Meteorological Agency, are taken from 1979 to 1982, and daily weathers of 1461 days are specified at 163 AMeDAS stations (Fig. 1). Each daily weather is specified as one of the five categories in Fig. 2. These categories are mutually exclusive.

Association of daily weather at two stations is examined as follows. Here X_{kA} and X_{kB} are respectively defined as the numbers of the kth category of daily weather at stations A and B. Then, the sample size, N, is expressed as follows;

$$N=\sum_{k=1}^{5} X_{kA}=\sum_{k=1}^{5} X_{kB}$$

In this investigation the sample size N is the number of days in a season. So Ns are 361 in winter (December, January and February), 368 in spring (March, April and May) and in summer (June, July and Agusust) and 364 in autumn (September, October and November). The probability of occurrence of the kth category of daily weather at stations A and B are respectively expressed as;

$$\frac{X_{kA}}{N}, \frac{X_{kB}}{N}$$

Then the probability that the kth category will happen at both the stations is as follows;

$$\frac{X_{kA}\,X_{kB}}{N^2}$$

Let P denote the probability that the same category will happen at both the stations. Then,

$$P=\sum_{k=1}^{5}\frac{X_{kA}X_{kB}}{N^2}$$

Dealing with discrete events (matching or mismatching of daily weather), the frequency distribution of matches is a binomial. A normal approximation to the binomial deviation from the mean is created by the following equation (Owen, 1962);

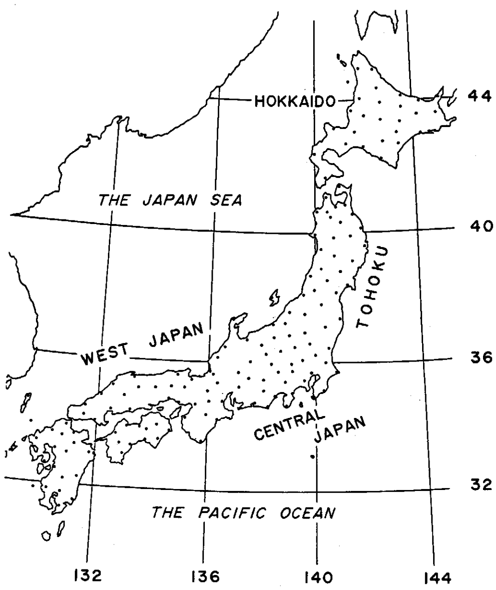


Fig. 1 Locations of AMeDAS stations to be analysed.

$$Z = \sqrt{N}(2\arcsin\sqrt{\frac{R}{N}} - 2\arcsin\sqrt{P})$$

where R denotes observed number of matches of daily weather. Using this normal approximation, the probability of obtaining observed number of matches (R) can be found by use of a table of cumulative probabilities for the standardized normal distribution.

In this investigation, occurrence of daily weather at two stations are determined to be associated each other, when the probability of obtaining observed number of matches is smaller than 0.1% (Z value is greater than 3.09). Namely, two stations are determined to be associated each other, when daily weathers at the stations correspond one another at a statistically significant level of 0.1%.

Here some terms are defined to be used in the following chapters. Ratio of the number of matches (R) to that of all the comparisons (N) is abbreviated as RM. Ratio of the number of matches of category k to N is abbreviated as RM of category k. In the following chapter association of daily weather is mainly investigated by distribution of stations associated with specified stations. These specified stations are referred to as key stations, and stations associated with a key station as associated stations.

3. Results

Here distributions of associated stations and RMs of respective categories are analysed, taking some key stations.

The case of key stations in the west of Hokkaido

The distribution of associated stations in winter is very much different from those in the other seasons.

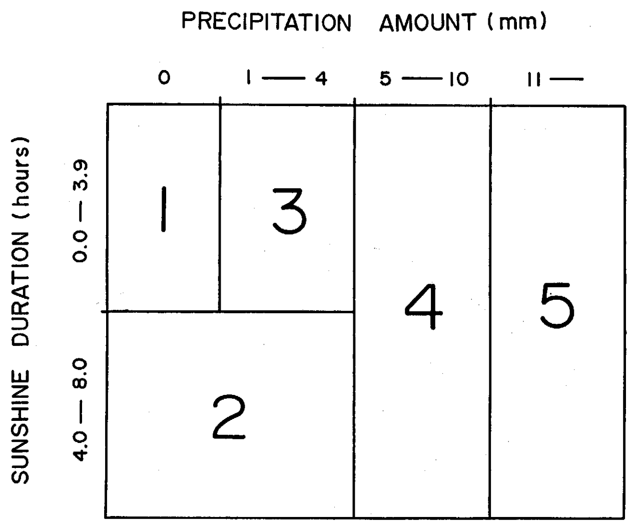


Fig. 2 The definition of daily weather categories.

In spring, summer and autumn, associated stations generally appear in almost all the parts of Hokkaido and on the Japan Sea side of Tohoku. RMs at associated stations are about 50 to 60%. Taking a case of a key station in the west of Hokkaido, association of daily weather is investigated in detail (Fig. 3(a)). In this case almost all the RMs at the associated stations are greater than 60%, RMs of category 2 are about 50% and RMs of categories 1 and 4 are about 7% and about 4%, respectively. On the other hand, at stations situated straight outside the dotted area in Fig. 3(a), RMs are about 50%, RMs of category 2 are about 45% and those of categories 1 and 3 are about 4% and about 1%, respectively.

In winter associated stations are generally situated in the west of Hokkaido and on the Japan Sea side of Tohoku. Taking a case of a key station, association is investigated in detail (Fig. 3(b)). In this case RMs at the associated stations are nearly 50%, and those of categories 1, 2 and 3 are about 25%, 20% and 6%, respectively. On the other hand, at stations located straight outside the dotted area RMs of each category are different for different locations of stations. RMs of category 2 at stations on the Pacific side and those on the Japan Sea side of Hokkaido and Tohoku are about 15% and 7%, respectively. RMs of category 1 at stations in Tohoku are about 15% and those in the east of

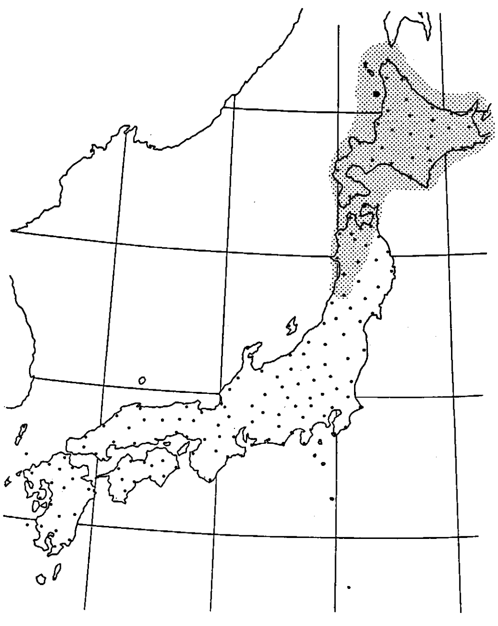


Fig. 3 (a) The distribution of associated stations in spring in the case of key station lying in the west of Hokkaido.
The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

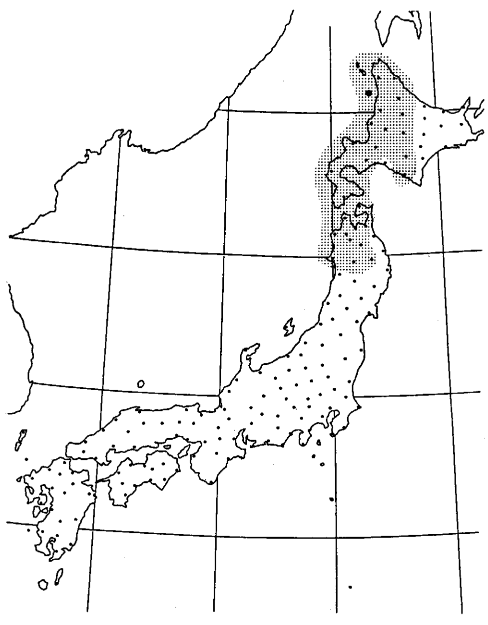


Fig. 3 (b) The same as (a), except for winter.

Hokkaido are about 10%. RMs of category 3 on the Japan Sea side of Tohoku are about 6%. It is nearly the same percentage as at the associated stations on the Japan Sea side of Tohoku. On the Pacific side of Tohoku and in the east of Hokkaido, RMs of category 3 are about 3%.

The case of key stations in the east of Hokkaido

Like the previous case, the distribution of associated stations in winter is different from those in the other seasons.

In spring, summer and autumn, associated stations tend to be situated in almost all the parts of Hokkaido and on the Pacific side of Tohoku. RMs at these associated stations are about 50 to 60%. This percentage is similar to those in the previous case. Association of daily weather is investigated in detail, taking a case of a key station in the east of Hokkaido (Fig. 4(a)). RMs at the associated stations are about 60% and those of categories 2 and 1 are about 50% and about 7%, respectively. At stations situated just outside the dotted area, RMs of categories 2 and 1 are about 40% and 4%, respectively.

In winter associated stations tend to be situated in the east of Hokkaido and on the Pacific side of Tohoku. Referring to a case (Fig. 4(b)), RMs at the associated stations are about 60%.And RMs of categories 2 and 1 are greater than 50% and about 6%, respectively. Like the case of Fig. 3(b), at stations located just outside the dotted area in

Fig. 4 (a) The distribution of associated stations in autumn in the case of key station lying in the east of Hokkaido. The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

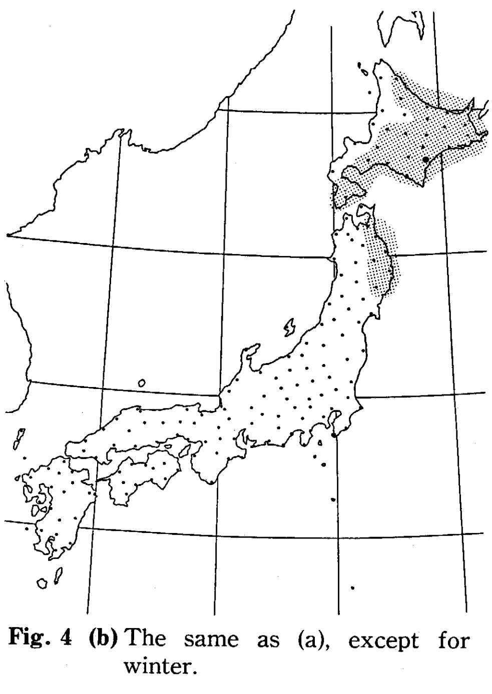


Fig. 4 (b) The same as (a), except for winter.

Fig. 4(b), RMs of each category are different for different locations. RMs of category 2 at stations on the Japan Sea side of Tohoku and in the west of Hokkaido are about 20%. On the Pacific side of Tohoku, to the south of the dotted area in Fig. 4(b), RMs of category 2 are greater than 50% which are nearly the same percentage as at the associated stations, and RMs of category 1 are about 3%.

The case of key stations on the Japan Sea side of Tohoku

Like the previous cases, distribution of associated statins in winter is considerably different from those in the other seasons.

In spring, summer and autumn, associated statons tend to be situated in almost allthe parts of Hokkaido and Tohoku and RMs at the associated stations are about 50% to 60%. Taking a case of a key station on the Japan Sea side of Tohoku (Fig. 5(a)), association of daily weather is investigated in detail. In this case RMs at the associated stations are nearly 60%. RMs of categories 1, 2 and 3 are about 7%, about 45% and about 5%, respectively. On the other hand, at stations just outside the dotted area, RMs of categories 1 and 2 area about 3% and about 40%, respectively. And almost all the RMs of category 3 are smaller than 2%.

In winter associated stations tend to be situated in the west of Hokkaido and on the Japan Sea side of Tohoku. Referring to a case (Fig. 5(b)), RMs at the associated stations

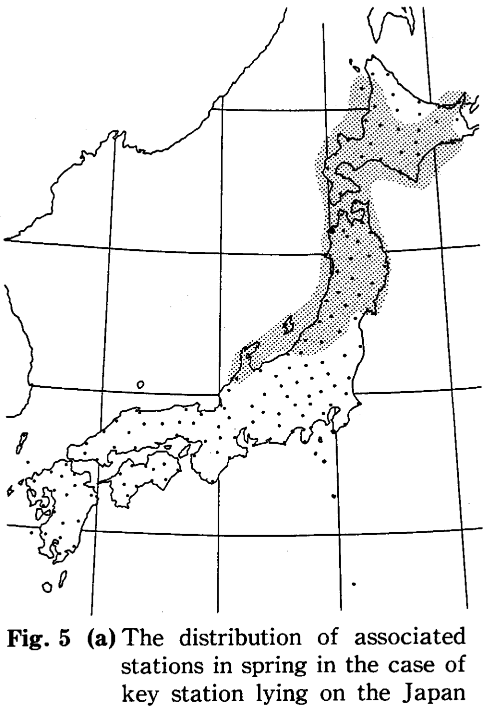


Fig. 5 (a) The distribution of associated stations in spring in the case of key station lying on the Japan Sea side of Tohoku. The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

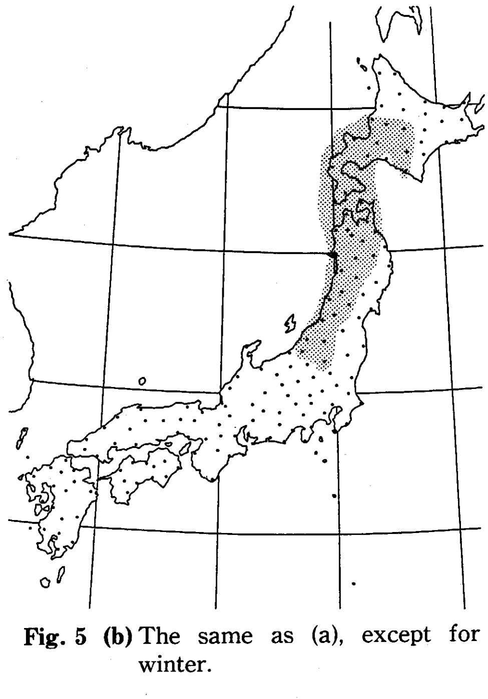


Fig. 5 (b) The same as (a), except for winter.

are only about 40%. RMs of categories 1 and 2 are respectively about 15%, and about 10% with respect to category 3. At stations just outside the dotted area, RMs of categories 1, 2 and 3 are about 7%, about 15% and about 3%, respectively. RMs of category 2 are almost the same percentage both inside and outside the dotted area.

The case of key stations on the Pacific side of Tohoku

Distribution of associated stations in winter is, like the previous cases, different from those in the other seasons.

In spring, summer and autumn, associated stations tend to be situated in the southern or eastern part of Hokkaido and in an area extending from Tohoku to Central Japan. RMs at associated stations are nearly 50% to 60%. Referring to a case (Fig. 6(a)), RMs at the associated stations are nearly 60%. RMs of category 2 are about 50%, and those of categories 1 and 3 are about 7% and 3%, respectively. On the other hand, at stations just outside the dotted area, RMs of categories 2, 1 and 3 are about 45%, about 3% and about 1%, respectively.

In winter associated stations tend to be situated on the Pacific side of Tohoku. Referring to a case (Fig. 6(b)), RMs at almost all the associated stations are about 60%. Those of categories 1 and 2 are about 10% and about 50%, respectively. RMs at stations just outside the dotted area are different for different locations of stations. At stations

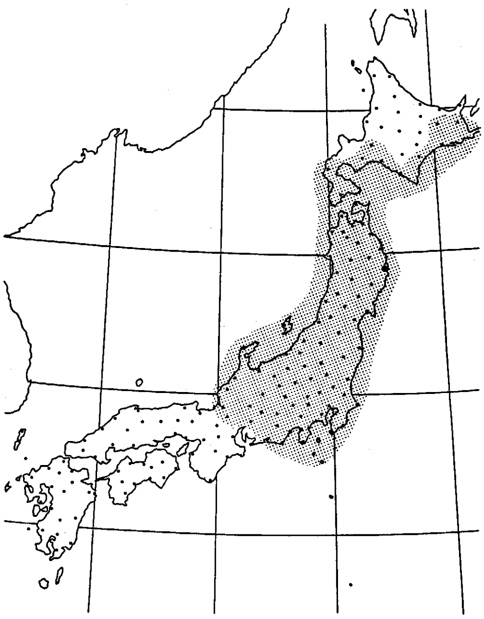


Fig. 6 (a) The distribution of associated stations in spring in the case of key station lying on the Pacific side of Tohoku. The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

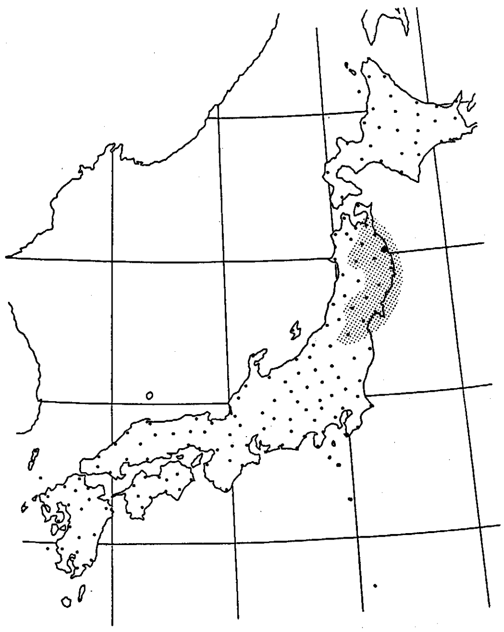


Fig. 6 (b) The same as (a), except for winter.

to the south of the dotted area on the Pacific side of Tohoku, RMs of category 1 are about 3% and those of category 2 are nearly the same percentage as the associated stations. At stations on the Japan Sea side of Tohoku, RMs of categories 2 and 1 are about 15% and about 6%, respectively. RMs of category 1 at stations in Hokkaido are about 3%, and those of category 2 in the east and the west of Hokkaido are about 50% and about 15%, respectively.

The case of key stations on the Japan Sea side of Central Japan

Distribution of associated stations in winter is different from those in the other seasons.

In spring, summer and autumn, associated stations extend spaciously from Tohoku to West Japan. RMs at associated stations are nearly 60%. Referring to a case (Fig. 7(a)), RMs are about 60%. RMs of categories 2, 1 and 3 are about 50%, about 5% and about 4%, respectively. At stations just outside the dotted area, RMs of categories 2, 1 and 3 are about 45%, about 2% and about 2%,respectively.

In winter associated stations tend to be situated on the Japan Sea side from Tohoku to West Japan. Referring to a case (Fig. 7(b)), RMs at the associated stations are about 35%. Those of categories 2, 1, 3 and 4 are about 15%, about 8%, about 8% and about 4%, respectively. At stations just outside the dotted area, RMs of category 2 are about the

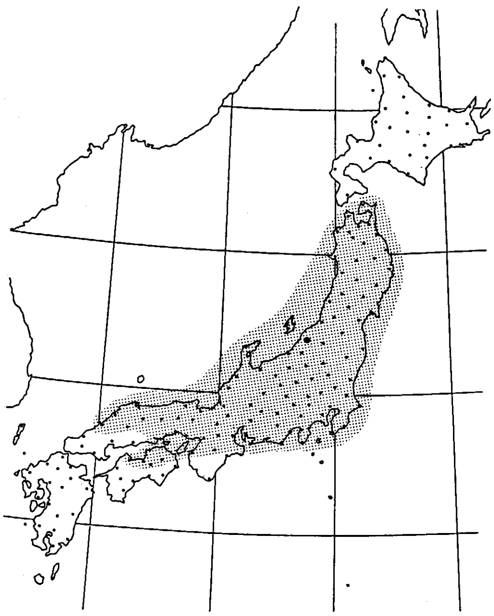


Fig. 7 (a) The distribution of associated stations in spring in the case of key station lying on the Japan Sea side of Central Japan.
The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

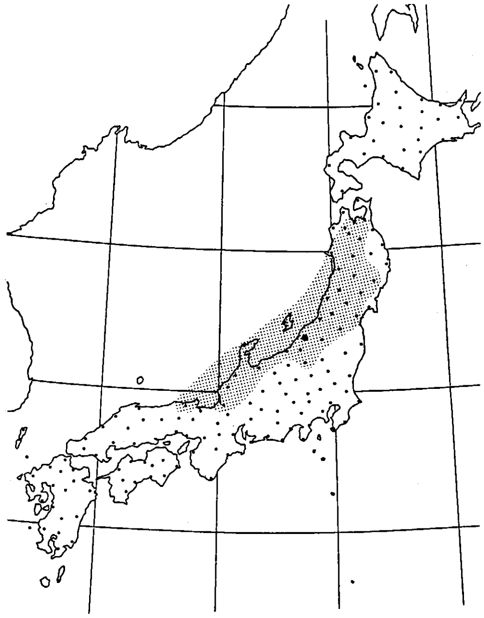


Fig. 7 (b) The same as (a), except for winter.

same percentage as those inside the dotted area. RMs of categories 1, 3 and 4 are about 4%, about 1% and smaller than 1%, respectively.

The case of key stations on the Pacific side of Central Japan

In spring, summer and autumn, associated stations tend to be situated in a spacious area extending from southern Tohoku to West Japan. RMs at associated stations are about 60%. Referring to a case (Fig. 8(a)), RMs at the associated stations are about 60%. RMs of category 2 are about 45% to 50%, and those of categories 1, 3 and 5 are about 8%, about 3% and about 3%, respectively. At stations just outside the dotted area, RMs of category 2 are about 40% to the west of the dotted area and about 35% to the north of the dotted area. Outside the dotted area, RMs of categories 1, 3 and 5 are about 4%, smaller than 1% and about 1%, respectively.

In winter associated stations tend to be situated on the Pacific side from southern Tohoku to West Japan. Referring to a case (Fig. 8(b)), RMs are high percentage of about 80%. Those of categories 2, 1 and 3 are about 70%, about 7% and about 2%, respectively. At stations just outside the dotted area, RMs of category 2 are different for different locations of stations. They are about 20% to the north and about 40% to the west of the dotted area. RMs of categories 1 and 3 are about 3% and smaller than 1%, respectively.

The case of key stations on the Japan Sea side of West Japan

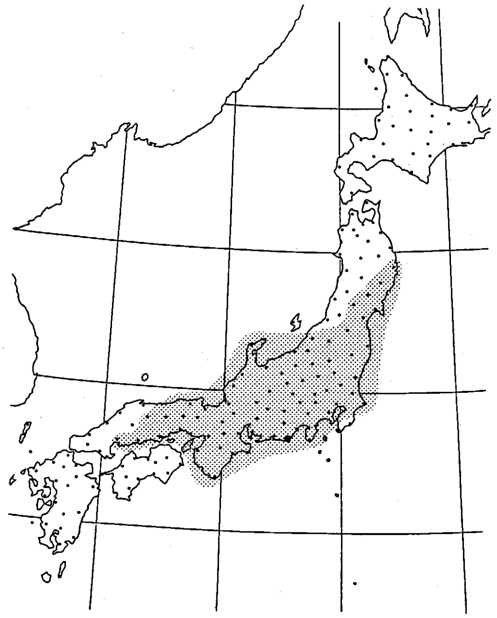


Fig. 8 **(a)** The distribution of associated stations in autumn in the case of key station lying on the Pacific side of central Japan. The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

Fig. 8 **(b)** The same as (a), except for winter.

In spring, summer and autumn, associated stations tend to be situated in a spacious area from West Japan to Central Japan, and to Tohoku as the case may be. Referring to a case (Fig. 9(a)), RMs at the associated stations are about 55%. RMs of categories 1 and 2 are about 8% and about 45% respectively. At stations just outside the dotted area, RMs of categories 1 and 2 are about 3% and about 40%, respectively.

In winter associated stations tend to be situated on the Japan Sea side of West Japan. Referring to a case (Fig. 9(b)), RMs at the associated stations are about 40%. RMs of categories 1, 2 and 3 are about 15%, about 20% and about 4%, respectively. At stations just outside the dotted area, RMs of categories 1 and 2 are about 6% and about 20%, respectively. Concerning category 3, RMs are about 1% or smaller, but on the Japan Sea side from Central Japan to southern Tohoku RMs are about the same percentage as in the dotted area.

The case of key stations on the Pacific side of West Japan

In spring, summer and autumn, associated stations tend to be situated in West Japan. Referring to a case (Fig. 10(a)), RMs at the assciated stations are about 55%. RMs of categories 1 and 2 are about 4% and about 45%, respectively. At stations just outside the dotted area, RMs of category 2 are about 40%. RMs of each of the other categories are slightly smaller than those at the associated stations.

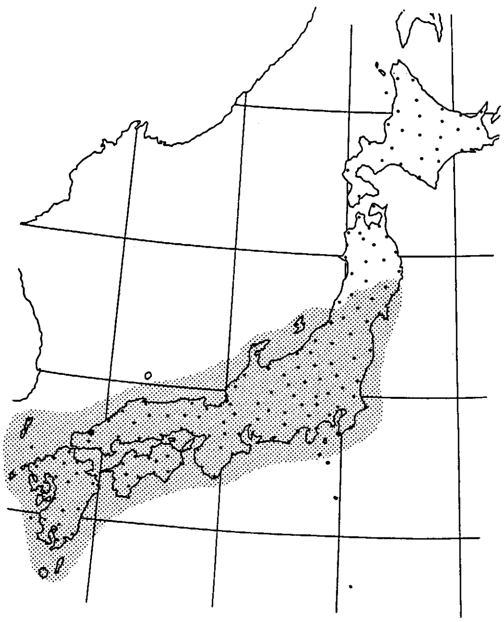


Fig. 9 (a) The distribution of associated stations in autumn in the case of key station lying on the Japan Sea side of West Japan. The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

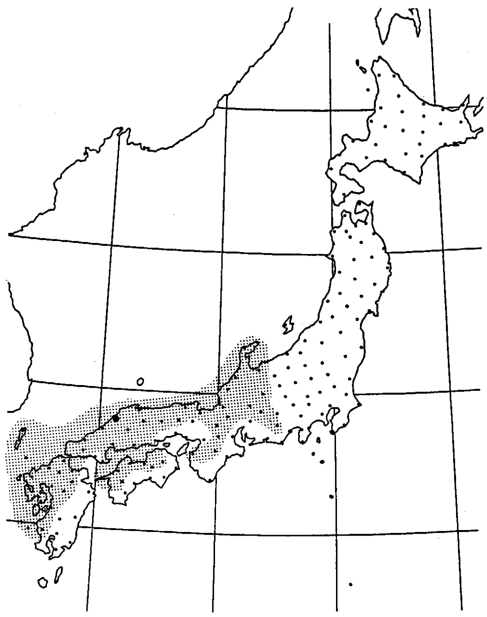


Fig. 9 (b) The same as (a), except for winter.

In winter associated stations tend to be situated on the Pacific side of West Japan. Referring to a case (Fig. 10(b)), RMs at the associated stations are about 75%, and those of categories 2 and 1 are about 70% and about 5%, respectively. At stations outside the dotted area, RMs of category 1 are nearly 3%. RMs of category 2 are different for different locations of stations; greater than 60% for the Pacific side of southern Tohoku, about 15% for the Japan Sea side of southern Tohoku, and about 40% for the Japan Sea side from Central Japan to West Japan.

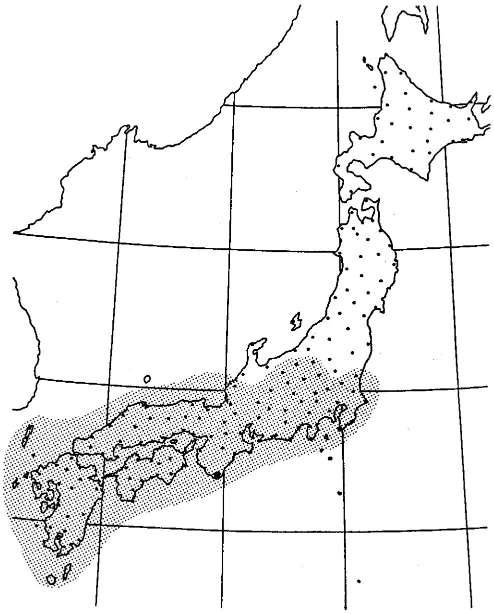


Fig. 10 (a) The distribution of associated stations in summer in the case of key station lying on the Pacific side of West Japan. The cluster of the associated stations is expressed as dotted area, and the large black disk denotes the key station.

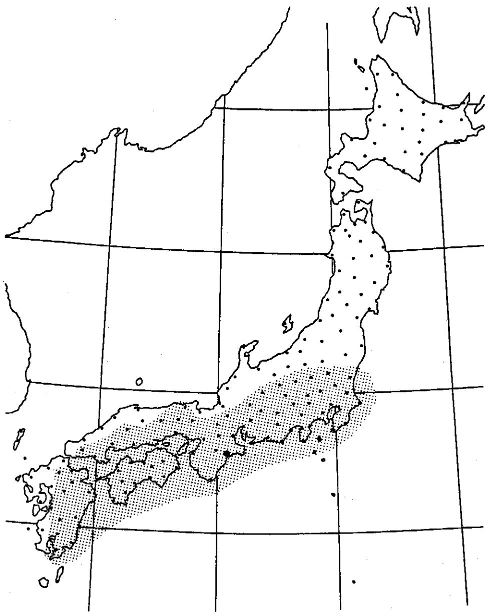


Fig. 10 (b) The same as (a), except for winter.

4. Discussion and Concluding Remarks

Consideration on categories restricting distribution of associated stations

When matching of a kind of category at two stations occurrs by chance, the category at one station does not associate with that at another station. Let p and q denote relative occurrence frequencies of a kind of category at two stations, respectively. Then ratio of chance matching of the category is expected to be pq. By comparing pq with actual RMs, it can be decided whether RMs analysed in the previous chapter are equal to ratios of chance matching or not. Here relative occurrence frequencies of respective categories are examined to obtain pq values.

In winter distributions of relative occurrence frequencies of respective categories show striking contrast between the Japan Sea side and the Pacific side.Concerning category 2, frequencies on the Japan Sea side are nearly smaller than 40% and those on the Pacific side are nearly greater than 70%. In the cases of the other categories, however, frequencies on the Japan Sea side are greater than those on the Pacific side. On the Japan Sea side, relative occurrence frequencies of categories 1, 3, 4 and 5 are nearly 30%, 10% to 30%, smaller than 10% and smaller than 5%, respectively. On the Pacific side, the frequencies of categories 1, 3, 4 and 5 are about 10%, about 5%, about 2% and about 1%, respectively.

In spring, in contrast with the case of winter, there is no striking biassed distribution in relative occurrence frequency of each category. The frequencies of each category are similar values at almost all the stations; 10 to 20% for category 1, 60 to 70% for category 2, about 10% for category 3 and about 5% for categories 4 and 5.

In summer, like the case of spring, relative occurrence frequencies of each category are similar at almost all the stations. The frequencies of categories 1, 2 and 3 are 15 to 30%, 50 to 60%, and about 10%, respectively. Those of both the categories 4 and 5 are about 5%.

In autumn, relative occurrence frequencies of each category at almost all the stations are nearly the same values as in the case of summer; about 20% for category 1, about 60% for category 2, about 10% for category 3 and about 5% for categories 4 and 5. Relative occurrence frequencies of each category are nearly similar values in spring, summer and autumn.

By comparing RMs of respective categories in the previous chapter with ratios of chance matching *(pq)* derived from above examined relative occurrence frequencies, we can estimate a category (or categories) which may place restrictions on the distributions of associated stations. In the following part of this section, this estimate is given regarding the respective cases analysed in the previous chapter.

The case of key stations in the west of Hokkaido

In spring, summer and autumn, RMs of category 2 at the associated stations are greater than those at stations just outside the dotted area in Fig. 3(a). However, RMs of category 2 at stations outside the dotted area as well as the associated stations are greater than ratios of chance matching *(pq)*. RMs of respective categories 1 and 3 at the associated stations are greater than ratios of chance matching, but those at stations outside the dotted area are nearly equal to ratios of chance matching. Consequently, the distribution of the associated stations seems to be restricted by RMs of categories 1 and 3.

In winter, RMs of categories 1, 2 and 3 at almost all the associated stations in Fig. 3(b) are greater than ratios of chance matching, respectively. RMs of respective categories 1, 2 and 3 at stations in the east of Hokkaido are nearly equal to ratios of chance matching. Categories 1, 2 and 3 seem to be the limiting categories in this part of the distribution. At stations to the south of the dotted area on the Japan Sea side of Tohoku, RMs of category 2 are nearly equal to ratios of chance matching. In this part of the distribution, category 2 seems to be the limiting category. At stations on the Pacific side of Tohoku, RMs of categories 2 and 3 are nearly equal to ratios of chance matching. Categories 2 and 3 seem to be the limiting categories in this part of the distribution.

The case of key stations in the east of Hokkaido

In spring, summer and autumn, RMs of category 2 at stations both inside and outside of the dotted area in Fig. 4(a) are greater than ratios of chance matching. RMs of categories 1 and 3 at the associated stations are greater than ratios of chance matching. But RMs of categories 1 and 3 at stations just outside the dotted area are nearly equal to ratios of chance matching. It seems likely that the distribution of the associated stations is restricted by RMs of categories 1 and 3.

In winter, at stations on the Pacific side of Tohoku, just to the south of the dotted area in Fig. 4(b), RMs of category 2 are greater than ratios of chance matching, but those of category 1 are nearly equal to ratios of chance matching. Category 1 seems to be the limiting category in this part of the distribution. RMs of categories 1 and 2 at stations in the west of Hokkaido and on the Japan Sea side of Tohoku are nearly equal to ratios of chance matching. Categories 1 and 2 seem to be the limiting categories in this part of the distribution.

The case of key stations on the Japan Sea side of Tohoku

In spring, summer and autumn, RMs of respective categories 1, 2 and 3 at the associated stations are greater than those at stations inside the dotted are (Fig. 5(a)). RMs of category 2 at stations just outside the dotted area are also greater than ratios of chance matching, but those of categories 1 and 3 at stations just outside the dotted area are nearly equal to ratios of chance matching. It seems likely that the distribution of the associated stations is restricted by RMs of categories 1 and 3.

In winter, RMs of respective categories 1, 2 and 3 at the associated stations in Fig. 5(b) are greater than ratios of chance matching. But at stations just outside the dotted area, RMs of respective categories are nearly the same percentage as ratios of chance matching. It seems likely that the distribution of the associated stations is restricted by categories 1, 2 and 3.

The case of key stations on the Pacific side of Tohoku

In spring, summer and autumn, RMs of respective categories at the associated stations of Fig. 6(a) are greater than ratios of chance matching. RMs of category 2 at stations just outside the dotted area are also greater than ratios of chance matching, but those of categories 1 and 3 are nearly equal to the ratios. It seems likely that the distribution of the associated stations is restricted by categories 1 and 3.

In winter, at stations on the Japan Sea side of Tohoku, to the west of the dotted area in Fig. 6(b), RMs of respective categories are nearly equal to ratios of chance matching. In this part of the distribution of the associated stations, categories 1, 2 and 3 seem to be the limiting categories. At stations on the Pacific side of Tohoku, to the south of the dotted area, and in the south of Hokkaido, RMs of category 2 are greater than ratios of chance matching, but those of categories 1 and 3 are nearly equal to ratios of chance matching. Categories 1 and 3 seem to be the limiting categories in these parts of the distribution.

The case of key stations on the Japan Sea side of Central Japan

In spring, summer and autumn, at stations just outside the dotted area as well as the associated stations (Fig. 7(a)), RMs of category 2 are greater than ratios of chance matching. But RMs of categories 1 and 3 at stations just outside the dotted area are nearly equal to ratios of chance matching. It seems likely that the distribution is restricted by categories 1 and 3.

In winter, at stations just outside the dotted area in Fig. 7(b), RMs of respective categories are nearly equal to ratios of chance matching. Categories 1, 2 and 3 seem to be the limiting categories of the distribution.

The case of key stations on the Pacific side of Central Japan

In spring, summer and autumn, like the previous case, RMs of category 2 are greater than ratios of chance matching at stations both inside and outside the dotted area in Fig. 8(a). RMs of categories 1, 3 and 5 at stations just outside the dotted area are nearly equal to the ratios. The distribution seems to be restricted by categories 1, 3 and 5.

In winter, at stations just outside the dotted area in Fig. 8(b), RMs of respective categories are nearly equal to ratios of chance matching. But at stations on the Pacific side, to the north and the west of the dotted area, RMs of category 2 are greater than ratios of chance matching. Categories 1 and 3 seem to be the limiting categories, and in the inland part of Central Japan category 2 seems to be also the limiting category.

The case of key stations on the Japan Sea side of West Japan

In spring, summer and autumn, at stations both inside and outside the dotted area in Fig. 9(a), RMs of category 2 are greater than ratios of chance matching. RMs of category 1 at the associated stations are greater than ratios of chance matching, but those at stations just outside the dotted area are nearly equal to ratios of chance matcing. The distribution seems to be restricted by category 1.

In winter, RMs of categories 1, 2 and 3 at the associated stations are greater than ratios of chance matching. However, those at stations just outside the dotted area in Fig. 9(b) are nearly equal to ratios of chance matching. It seems likely that categories 1, 2 and 3 are the limiting categories of the distribution.

The case of key stations on the Pacific side of West Japan

In spring, summer and autumn, RMs of category 2 are greater than ratios of chance matching at stations just outside the dotted area as well as the associated stations (Fig. 10(a)). RMs of respective categories 1 and 3 at the associated stations are somewhat greater than ratios of chance matching, but those at stations outside the dotted area are nearly equal to ratios of chance matching. The distribution seems to be restricted by categories 1 and 3.

In winter, at stations just outside the dotted area on the Pacific side of Tohoku as well as the associated stations (Fig. 10(b)), RMs of category 2 are greater than ratios of chance matching, but those at other stations just outside the dotted area are nearly equal to ratios of chance matching. RMs of category 1 at the associated stations are greater than ratios of chance matching, but those at stations just outside the dotted area are nearly equal to ratios of chance matching. In the part of the distribution bordering on the Pacific side of Tohoku, category 1 seems to be the limiting category, but in the other parts categories 1 and 2 seem to be the limiting categories.

Consideration on the factors restricting the distribution

In spring, summer and autumn, RMs of category 2 are greater than ratios of chance matching at associated stations and stations just outside clusters of associated stations. According to the definition of categories, category 2 represents fine weather and tends to appear spaciously under the condition of migratory high. (Fig. 11). This spacious appearance of category 2 may cause the fact that RMs of category 2 are greater than ratios of chance matching even at stations just outside clusters of associated stations. Categories 1 and/or 3 restrict distributions of associated stations. According to the definition, categories 1 and 3 represent bad weather and tend to appear in and around disturbances such as cyclones. It seems that disturbances restrict distributions of associated stations in spring, summer and autumn.

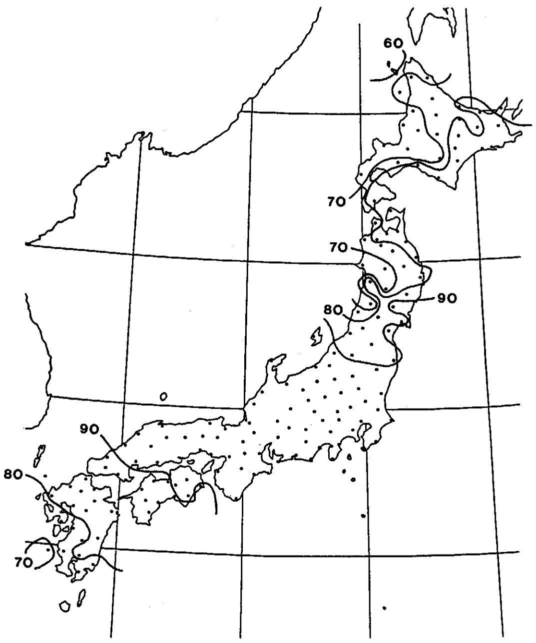


Fig. 11 The distribution of relative occurrence frequencies (%) of category 2 in the case of centers of migratory highs located over West or Central Japan at 9 JST. (36 samples).

Here relations between disturbances and distributions of associated stations are examined. When cyclones moving northeastwards are situated at 9 JST in the northern Japan Sea or in the vicinity of Hokkaido, relative occurrence frequencies of category 2 in Tohoku and Hokkaido are smaller than in the other part (Fig. 12). These situations of disturbances may be ones of the factors restricting the distributions of associated stations when key stations are situated in Tohoku or Hokkaido. When cyclones or fronts are situated off the Pacific coast of West or Central Japan at 9 JST, relative occurrence frequencies of category 2 are smaller from Central to West Japan than in the other part (Fig. 13). These situations of disturbances may be ones of the factors restricting the distributions when key stations are situated on the Pacific side of Central Japan. However, a single situation of disturbance does not explain a single distribution of associated stations. It is a matter of course, because distributions of associated stations are products of daily occurrences of categories under various conditions of disturbances.

In this investigation, daily weathers at one specified key station are compared with those at other respective stations. Daily weathers at one associated station are not compared with those at another associated stations. So it may happen that at all the associated stations the same category rarely occurres on the same day. From the beforementioned fact that no single situation of disturbance explain a single distribution of associated stations, following attention must be paid to the interpretation of the distribution: The distribution revealed in the previous chapter emerges as the result of recurrent matching of limiting categories at one specified key station and unfixed part of associated stations.

Considering the attention to the interpretation of the distribution and the limiting categories 1 and 3 tend to appear in and around disturbances, a model explaining emergence of the distribution can be made in the following way: It seems that spheres of bad weather migrate eastwards as disturbances move eastwards. When easternmost sphere of bad weather comes to specified key station at 16 JST, westernmost sphere of bad weather at 8 JST may restrict westernmost associated station as illustrated in the case 1 of Fig. 14(a). When westernmost sphere of bad weather at 8 JST is at the key station, easternmost sphere of bad weather at 16 JST may restrict easternmost

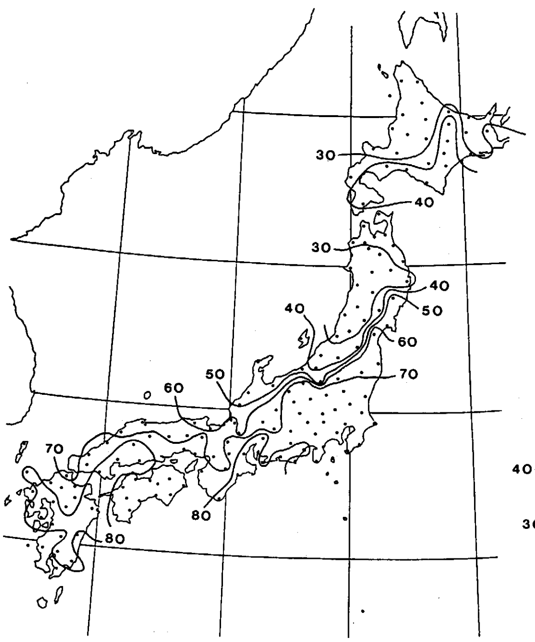


Fig. 12 The distribution of relative occurrence frequencies (%) of category 2 in the case of disturbances located in the vicinity of Hokkaido at 9 JST. (29 samples).

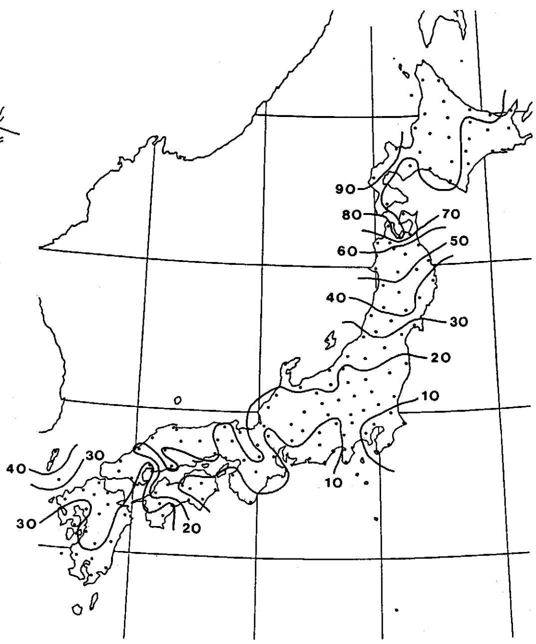
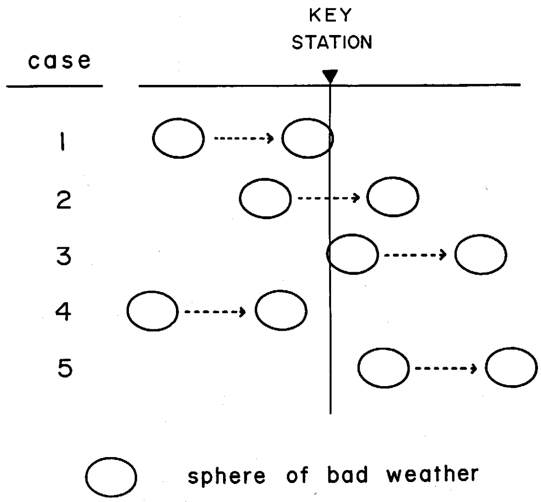
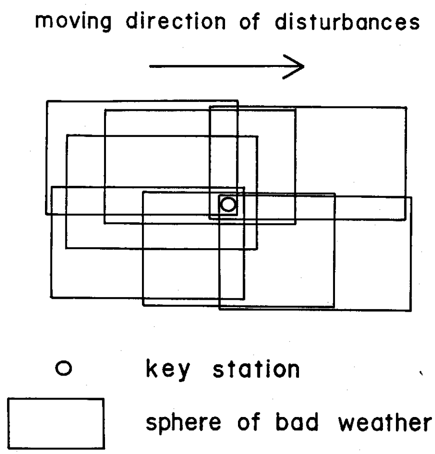


Fig. 13 The distribution of relative occurrence frequencies (%) of category 2 in the case of disturbances located to the south of Pacific coast of West Japan at 9 JST. (21 samples).

associated station as illustrated in the case 3 fo Fig. 14(a). Locations of disturbances are not restricted by time. So during 8 hour time interval spheres of bad weather frequently migrate from west to east of the key station as illustrated in the case 2 of Fig. 14(a). Bad weather of this case may also contribute to the distribution of associated stations. However, bad weather does not contribute to the distribution when sphere of bad weather does not pass the key station during 8 hour time interval as illustrated in the cases 4 and 5 of Fig. 14(a).

Itoyama (1961) analysed locations of disturbances bringing precipitation to a specified station. According to his result, sphere of precipitation may extend zonally for about 500 km and meridionally for about 350 km around disturbances. Estimating eastwards moving speed of disturbances at about 40 km/hr, moved distance of disturbances from 8 to 16 JST comes to about 300 km. So sphere of bad weather in eight hours may have zonal extent of more than 1300 km and meridional extent of more than 700 km. By the way, locations of disturbances are not restricted by time, as mentioned before. So spheres





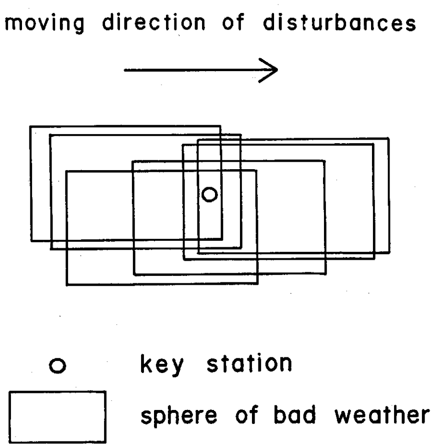


Fig. 14 Schematic model explaining distributions of bad weathers brought by moving disturbances. See text.
(a) : Upper left ;
(b) : Upper right ;
(c) : Lower.

of bad weather may be widely distributed as illustrated in Fig. 14(b).

It is well known that disturbances around Japan tend to take some fixed paths. According to Shibayama (1954) and others, main paths are as follows;

(1) eastwards off the Pacific coast of West and Central Japan and then straightforwardly,

(2) eastwards off the Pacific coast of West and Central Japan and then northwards off the Pacific coast of Tohoku to the east of Hokkaido,

(3) northeastwards along the Japan Sea coast of West and Central Japan and then to the east of Hokkaido,

(4) northeastwards from Korean Peninsula to the east of Hokkaido,

(5) eastwards along the circle of about 50°N.

Disturbances tend to move along the fixed paths and locations of disturbances are not restricted by time. So spheres of bad weather may distribute along the paths (Fig. 14(c)) and areas, where stations tend to have the same limiting categories as key stations, may have the greatest dimension along the paths, ordinarily in zonal direction. Consequently zonally elongated area of associated stations may appear on zonally extending land. It may hold true for the cases of key stations lying in West or Central Japan (Figs. 7(a), 8(a), 9(a) and 10(a)). Judging from locations and moving directions of disturbances, disturbances moving eastwards along the western parts of the abovementioned paths (1), (2) and (3) may restrict the distributions of associated stations in these cases.

Areas of associated stations may have smaller dimensions in meridional direction than in zonal direction. It may hold true for the cases of key stations lying in Hokkaido and on the Japan Sea side of Tohoku (Figs. 3(a), 4(a) and 5(a)). Actually areas of associated stations in these cases have small meridional extents, compared with zonal extents in the cases of key stations lying in West and Central Japan. Judging from locations and moving directions of disturbances, disturbances moving eastwards along the eastern parts of the paths (3) and (4) may restrict the distributions of associated stations. Developed disturbances taking the path (5) may also restrict the distributions.

Comparing two cases of key stations lying on the Pacific and the Japan Sea sides of Tohoku, southward extent of the area of associated stations in the former case is greater than in the latter case (Figs. 6(a) and 5(a)). This difference in the southward extent may be caused by disturbances moving northwards along the path (2). These northwards moving disturbances off the Pacific coast of Tohoku may also restrict the northeastern part of the distribution in the case of the key station lying on the Pacific side of Central Japan (Fig. 8(a)).

In winter, unlike the other seasons, there are striking contrasts of RMs of category 2 as well as other categories between the Pacific and the Japan Sea sides. By the way it is well known that the combination of winter monsoon and topography of Japan causes bad weathers on the Japan Sea side and fine weathers on the Pacific side. This contrast of weathers between both the sides is consistent in the abovementioned contrasts of RMs. In winter, as well as in the other seasons, disturbances pass in and around Japan and have some influence on winter weather. However, these disturbances cannot explain the striking contrasts of RMs between both the sides. As discussed before, combination of winter monsoon and large-scale topography of Japan brings large-scale contrasts of weather between both the sides. This large-scale contrast of weather may determine inland confines of the areas of associated stations. By the way, each area of associated stations does not cover the whole but part of either side. Locations of confines of the areas are partially similar to those in the other seasons. So confines of the areas, excluding inland parts, may be determined by disturbances, like in the other seasons, and/or local difference in bad and fine weathers brought by winter monsoon and local topography.

Concluding remarks

Regarding distributions of associated stations, the followings are revealed:

1. In spring, summer and autumn

   When key stations lie in Hokkaido or Tohoku, associated stations tend to distribute in part of Hokkaido and Tohoku. When key stations lie in Central or West Japan, associated stations tend to distribute in spacious area from West to Central Japan.

2. In winter

   The distributions of associated stations are similar to those in the other seasons, except of the following points. When Key stations lie on the Japan Sea side, associated stations tend to distribute in part of the Japan Sea side, and associated stations tend to distribute in part of the Pacific side when key stations lie on the Pacific side.

Regarding factors restricting distributions of associated stations, the followings are estimated:

1. In spring, summer and autumn

   The distributions may be restricted by categories 1 and/or 3. Weathers of categories 1 and 3 may be brought by disturbances. Judging from paths of disturbances and the distributions of associated stations, respective distributions may be restricted by disturbances on locations peculiar to the distributions.

2. In winter

   The distributions of associated stations may be restricted by categories 1, 2 and/or 3. Inland boundaries of the distributions may be restricted by winter monsoon and large-scale topography which cause well known contrast of weathers between the Pacific and Japan Sea sides. The other parts of the boundaries may be restricted by disturbances like in the other seasons, and/or local difference in bad and fine weathers brought by winter monsoon and local topography.

There are problems regarding method of identifying associated stations and definition of categories. Identification of associated stations was carried out by comparing weather sequence at one key station and that at each of the other stations. So it is uncertain whether same weather categories tend to appear at all or at part of the associated statons. Weather categories are defined based on both sunshine duration and precpitaton amount from 8 to 16 JST. As weather categories are not strictly defined, same categories do not always mean same actual weathers. For instance, heavy rain in the first few hours and in the last few hours may result in the same category. By the way, presuming that limiting categories in spring, summer and autumn were accompanied with disturbances, locations of disturbances restricting distributions of associated stations were conjectured based on paths of disturbances and the distributions. However, this conjecture cannot be fully certified, because of the abovementioned problems regarding method and definition. It also holds true for the conjecture of the limiting factors in winter. It will be one of the important subjects of study to investigate further both distribution of weather and its limiting factor by improving definition of weather and method.

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(*in Japanese, **in Japanese with English abstract, ***in Japanese with German abstract)