MACRO-SCALE AIRFLOW PATTERNS IN THE JAPANESE ISLANDS

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Abstract Daily surface wind distributions in the Japanese Islands in 1973 are classified by cluster analysis. As a result, twelve macro-scale airflow patterns are clarified. Their resultant wind patterns are characterized as follows: southwesterly wind or sea breeze (a1-a4 type), northeasterly wind (b1-b3 type), and northwesterly wind (c1-c5 type). Applying discriminant analysis to the other years, the daily patterns are clarified from 1968 to 1977. According to their frequency in the calender pentad, the periods in which each type prevails are as follows: summer (a1-a4 type), spring or autumn (b1-b3 type) and winter (c1-c5 type). Furthermore, the macro-scale airflow patterns are considered good indicators of the climate in the Japanese Islands.

1. Introduction

As for the atmospheric system, the climate should be clear if it is researched comprehensively. Investigating the climate using the synthesis of the weather elements variation, the time variation and the space variation (Godske, C. L., 1966), the climate will be so simplified. Because there are plenty of elements it seems to be difficult to study climate in such a way. But in the atmospheric system unified parts are usually found. Classifying the parts, it is easy to compose the climate from these unified parts. Recently, multivariate analysis has developed, so it has become easy to investigate the climate comprehensively.

The unified parts correspond to specific weather patterns. These may be classified on the basis of the airflow system. The airflow system is considered to be caused by orographic modification. So, the airflow system may have characteristic patterns which relate directly to the surface climatic elements.

There are many works in which the airflow patterns were used in Japan (Jacobs, 1946; Maejima, 1954; Numata, 1955; Kawamura, 1961; Shitara, 1966). In each analysis, the meso-scale area such as Hokkaido was chosen. Usually, the airflow was set up by dividing the gradient wind direction into eight. In some cases, the pressure patterns were used supplementary. Thus, the airflow pattenrs were simple indexes of synoptic climatological field. Then, using the airflow patterns, the distribution of precipitation and so on were analyzed. But, heterogeneous cases may get mixed in each airflow patterns. So, they have had problems about simultaneity and origin of the result.

Another method was used to set up airflow patterns. The classified surface wind distributions were used as the criterion to classify the gradient wind direction (Kawamura, 1966).

That is to say, selecting the days of specified pressure patterns, drawing surface streamline maps for each day, classifying them, the airflow patterns were set up by the surface gradient wind directions and curvature of each group. At the same time, it was confirmed that the surface wind distribution. So, the airflow patterns provided a concrete foundation as an index of synoptic climatological field. Afterwards, this method was applied to the whole year, instead of just the winter season (Kawamura, 1970). It was applied all over Japan for each meso-scale area (Kawamura, 1977).

The former airflow patterns were set up by single gradient wind direction. This method had some problems. Firstly, the gradient wind direction might not usually be a straight line especially in the large area. When the Japanese Islands were used, it could be divided into five districts (Maejima, 1954; Kawamura, 1964, 1977). So, a complex procedure was necessary to grasp the characteristics of the whole Japanese Islands. These were assumed from the appearance of airflow patterns for each area at the same time. Secondly, the same gradient wind direction did not always represent the same synoptic climatological field. Sometimes cyclone and anticyclone had to be taken into consideration. So, on the airflow patterns, the curvature of isopress had to also be used. That is, part of the pressure system in special cases were used for the airflow patterns. The mean of gradient wind direction had been lost.

To overcome such problems that the airflow pattern of single gradient wind direction contains, it is necessary to set up macro-scale airflow patterns for the Japanese Islands. The airflow system, the fundamental unit to set up the airflow pattern, is considered as it spreads over the large area. For, surface wind in local areas changes with the pressure pattern such as west-high/east-low type variation. It is ascertained statistically that the temperature in local area is different by the pressure pattern (Hohgetsu, 1979). Also, the surface wind distribution in the Japanese Islands expresses the airflow system. It seems to be as large as the pressure system. For example, westerly winds blow over the whole area on the west-high/east-low type. Roughly southwesterly winds blow on the Japan Sea low type.

Grasping the airflow system allows macro-scale airflow patterns to be used as the index of united atmospheric phenomena. At least, that analysis seems to express the phenomena occurring simultaneously over macro-scale areas and clarifies the processes relating to them. In this work, the concrete method to set up such macro-scale airflow patterns will be examined. Also, the macro-scale airflow patterns will be used to analyze the climate of the Japanese Islands.

2. Setting Up the Macro-Scale Airflow Patterns

Examination of data

Area

In the Japanese Islands strong winds blow in winter on the coasts and islands, while in spring they blow inland (Kurashima, 1966). The annual variation of wind speed is classified into five types. They are mountain, Japan Sea side, cape and island, plane, and inland (Yoshino, 1966). Thus, it is sure that the wind is affected by the local topography. But the wind speed will be standardized to negate these local topographic influence. Then, the features of macro-scale wind will be clarified using their annual variation.

According to them, the period of maximum wind speed is different in each area. It is as follows:

(period of maximum wind speed)	(area)
winter-spring	coast of Northern Japan, Japan Sea side of Southwestern Japan
spring	inland of Northeastern Japan, Pacific Ocean side of Southwestern Japan
spring-summer	western part of Kyushu
summer-winter	Southwestern Islands

In those, summer-winter type is different from the others. The wind is stronger in autumn than in spring. So, there may be a boundary between Southwestern Islands and Kyushu.

Period

Annual variation of wind is actually large. The changes of wind speed with height is different in each season (Kusano, 1960). So, the airflow patterns based on the upper gradient wind direction used to be set up in a certain season. If the surface gradient wind direction is the same, a similar wind distribution should appear. That pattern is independent from the season. So, the airflow patterns were set up over a year (Kawamura, 1977). In this study the macro-scale airflow patterns based on the surface wind distribution itself will not be affected at all by problems of seasonal change.

Representative time

Especially on inlands, diurnal variation of wind was larger than annual variation of wind (Yoshino, 1966). The diurnal variation of wind was investigated based on the monthly mean wind speed every three hours. The time when the daily maximum wind speed occurred was about 15 JST. Comparing the surface wind system of 03, 09, 15 JST, there was not any difference between 09 and 15 JST (Kawamura, 1977). Consequently, in the day time, wind is so strong that the observed values of wind are representative over time and space. The strong wind in the day time is caused by the upper wind. So, its surface wind distribution may express characteristics on a macro-scale wind.

Examination of the method

Problems of subjective method

The surface wind distribution was usulaly classified subjectively (Kodama, 1966). But, if the chosen area is more extensive, the subjective classification is difficult. This is because not only are the stations many but also the wind systems in various scales are mixed. In this case, the streamline will be used to express the characteristics. If the wind distribution was simplified by the streamline it should be able to be classified (Kawamura, 1966). But the result of classification may be modified by various statistical operations.

Need for objective method

"Correlation method" has been adopted to classify the pressure distribution and the upper level height distribution (Lund, 1963; Nomoto and Tatsumi, 1972; Arai and Yajima, 1976). In that method, correlation coefficient of each distribution map was calculated. Then, the map having most number of maps whose correlation coefficient was over the standard value was selected as the pattern. But the standard value was almost baseless. So, the means of the pattern and relation between each pattern were not clear.

Cluster analysis was adopted to classify the area for climatic elements or direction of deformation tree. Then, the climatic area was set up by its characteristics (McBoyle, 1971; Kai, 1977). In this method, the scale which indicates the similarity of compared sample is set up. Then the most similar pair is combined to cluster. The method does not need a previously classified standard.

Atmospheric phenomena are usually homogeneous over time and space. So, it is difficult to find the key points or typical pattern in surface wind distribution. In the objective method, even if the maps seems to be almost the same, the difference should be evaluated quantitatively. Of course, in the objective method, the process of analysis is clear.

With cluster analysis, the individuals will be classified only by their own similarity (Okuno, *et al.*, 1971). To classify the surface wind distribution, there is not a problem about the analysis and the normalization of vector in this method.

Classification of surface wind distribution by cluster analysis

Based on the preceding examination, the surface wind distribution will be classified by cluster analysis to set up the macro-scale airflow patterns in the Japanese Islands. The processes are as follows:

(i) The area from Hokkaido to Kyushu is chosen. There are 137 meteorological stations excluding the mountain and plateau stations (Fig. 1). They are recorded on the MT (SDP tape) which is set by the Japan Meteorological Agency. The year 1973 is chosen. It is represented by the daily 15 JST wind direction and speed.

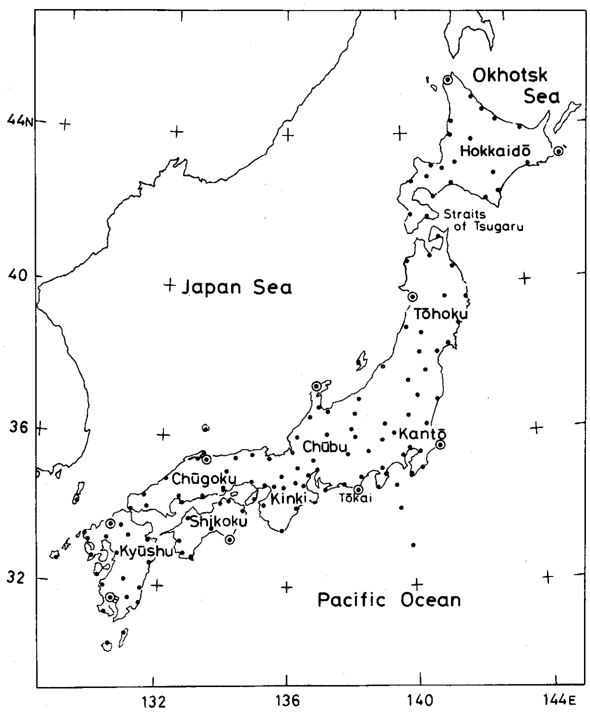


Fig. 1 Location of the objective meteorological stations whose data was used in this study (double circle; for discriminant analysis)

(ii) The similarity of two surface wind maps is defined. It is affected by the characteristics of macro-scale wind but not by local-scale wind. Firstly, the difference at the same station on other occasion is calculated. Then, the similarity of two compared maps is indicated by the total of all stations.
(iii) According to the similarity, the similarity matrix between each map is calculated.
(iv) Pairs of maps whose similarity is the highest are all combined. The method which produces plural cluster by one step is called weighted pair group analysis.
(v) The similarity matrix between the new combined clusters and the former maps are calculated again. That is based on the revolved definition of distance. In this case, the group average method is used. It affects the whole maps which consist of the cluster.
(vi) It is repeated to combine the cluster and to calculate the similarity. The process of the cluster combining and the relation between clusters are simply expressed by dendrogram (Fig. 2).
(vii) By the dendrogram, the most available clusters are decided. New cluster will be usually combined with the increase of distance. Occasionally, the cluster will not be combined in spite of the increase of distance (Fig. 3). In the case of level I or level II, the variance should be larger between rather than within the clusters themselves. That is to say, it is considered that each cluster is well unified.
(viii) On the level I, there are 12 clusters which consist of eleven or more individuals, while there are 7 comprising those of six to ten individuals. So it may be considered that the clusters which consist of eleven or more individuals are numerous. Then, the clusters which consist of eleven or more individuals are considered as reasonable clusters. There are 12 clusters and they are made into 3 principal clusters.

Statistical examination of the clusters

The clusters may be examined for their reasonableness in several ways. One is the minimum variance or t-test. The distribution map which consisted of a number of n-stations is considered to take a point in n-dimensional space. So, if each cluster is reasonable, it should occupy a particular place in the n-dimensional space. In that case, the clusters are well distinguished by the discriminant analysis. Then if the result of the analysis is good enough, the clusters should be reasonable.

The discriminant analysis is adopted for the 12 clusters. Firstly, the discriminant function is set up between a pair of clusters and the whole function is set up in 12 clusters with each other. Then, the nearest group will be clarified for each individual by adopting these discriminant functions. The results were good. Only 5 individuals were found to be misclassified in the 212 individuals. Then the macro-scale airflow patterns in the Japanese Islands are defined based on the 12 clusters. The number of clusters seems to be too little for the area. But, if the Japanese Islands were divided into five districts, the airflow patterns should be usually the same in the adjacent districts at the same time (Maejima, 1954; Kawamura, 1964). So, the number of the macro-scale airflow patterns should not be so many.

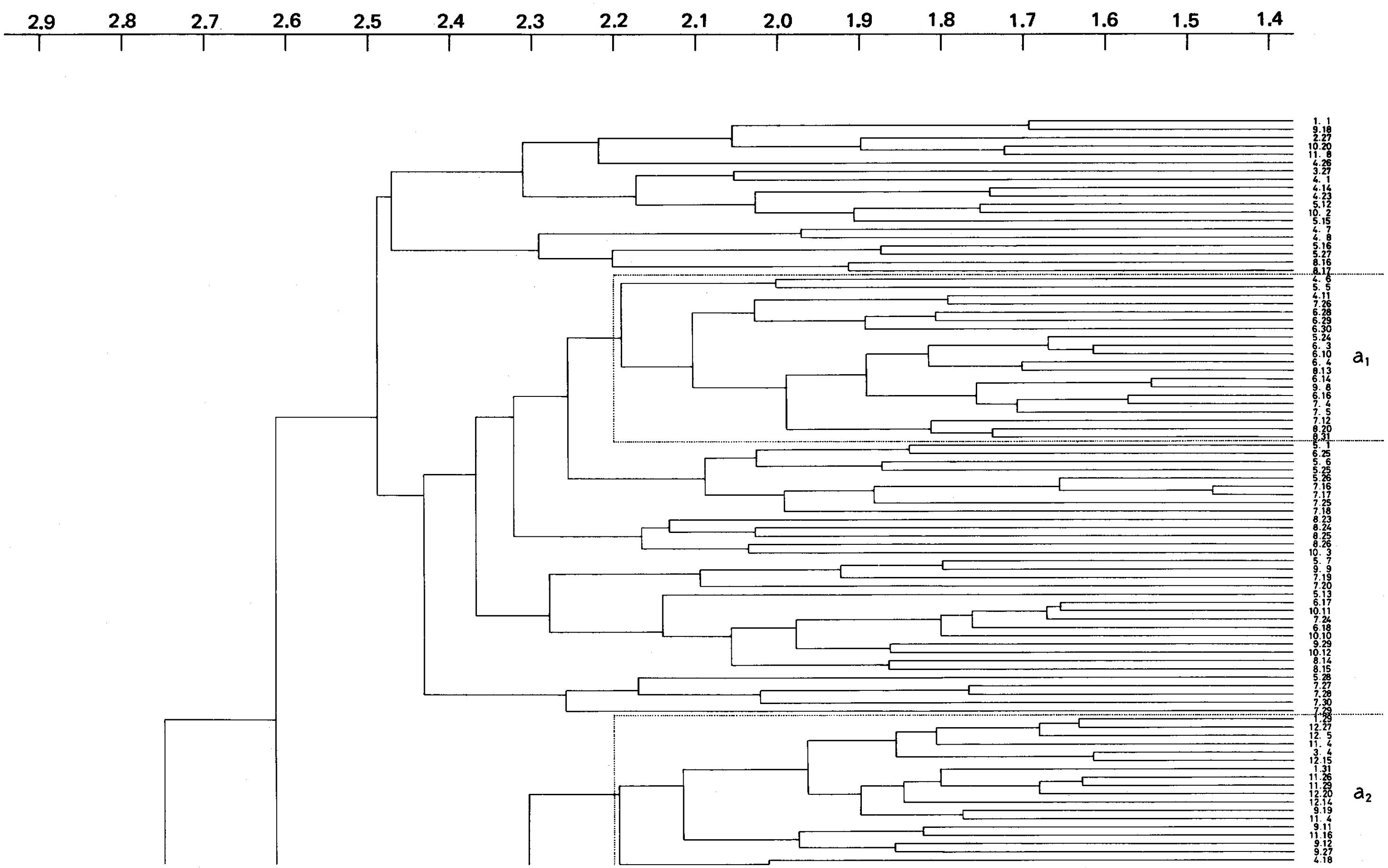


Fig. 2 Dendrogram of 365 days clustered by distance index of surface wind distribution

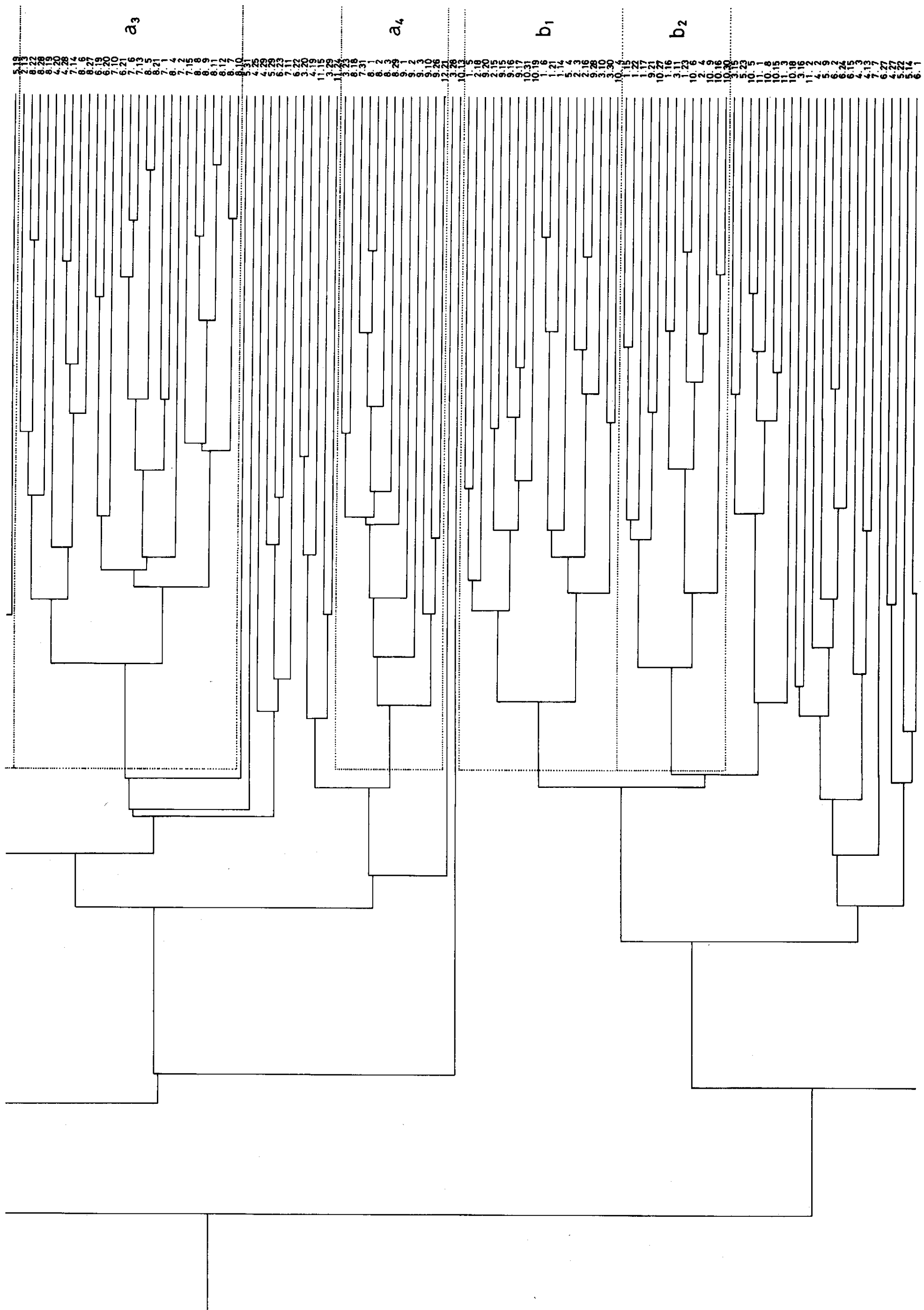
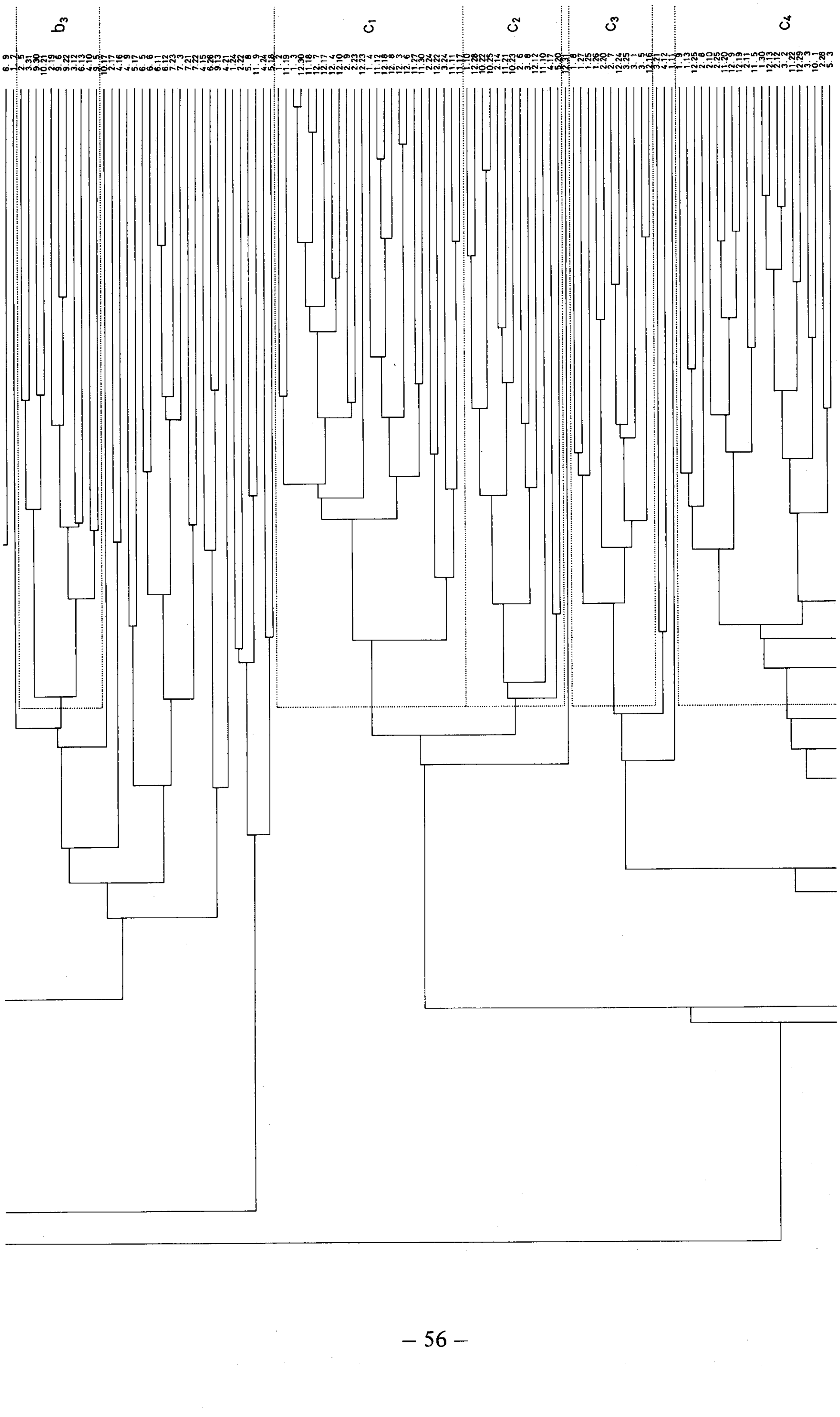


Fig. 2 (continued)



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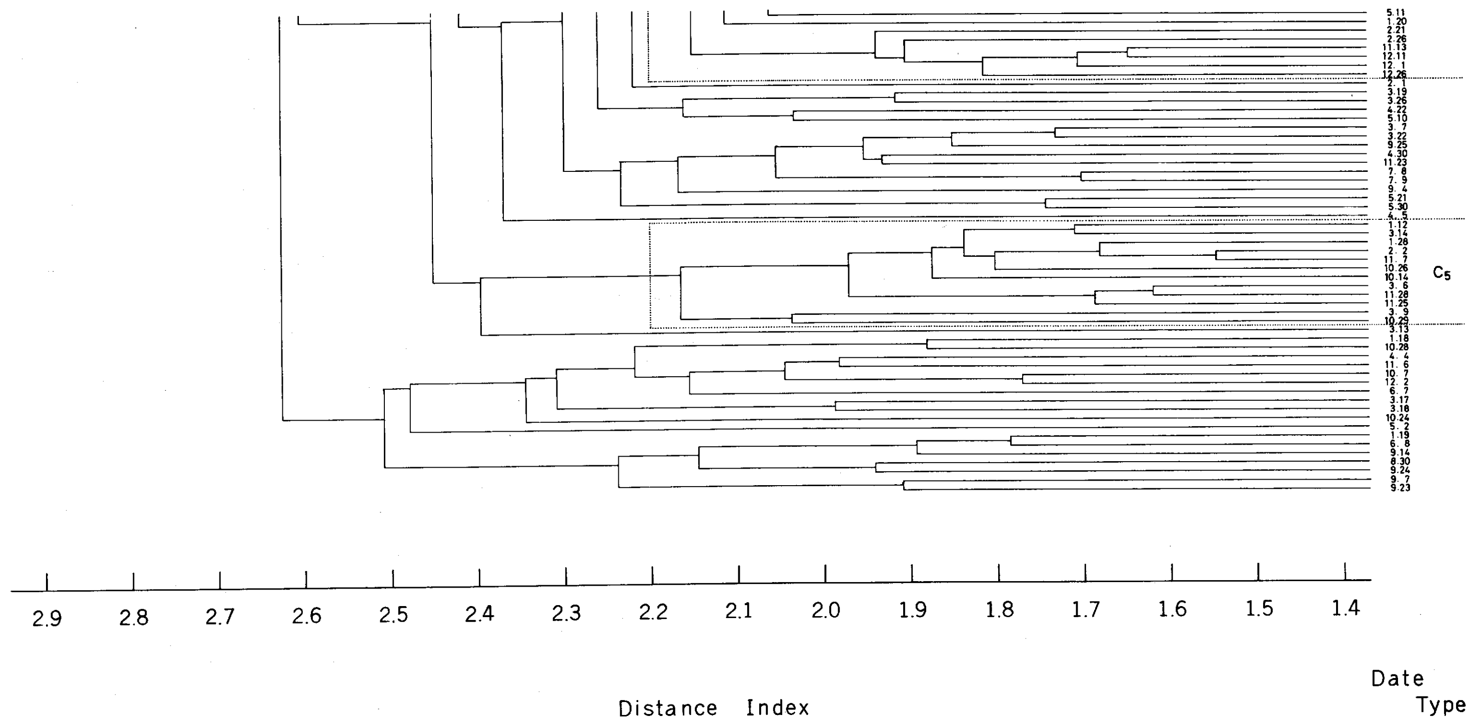

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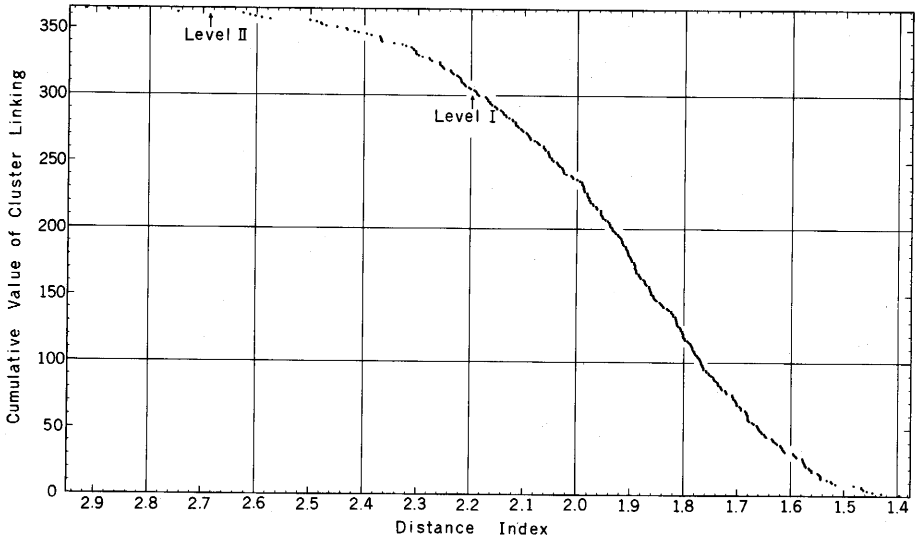


Fig. 3 Cumulative value of cluster linking against distance.

3. Characteristics of the Macro-scale Airflow Patterns

Surface wind distribution

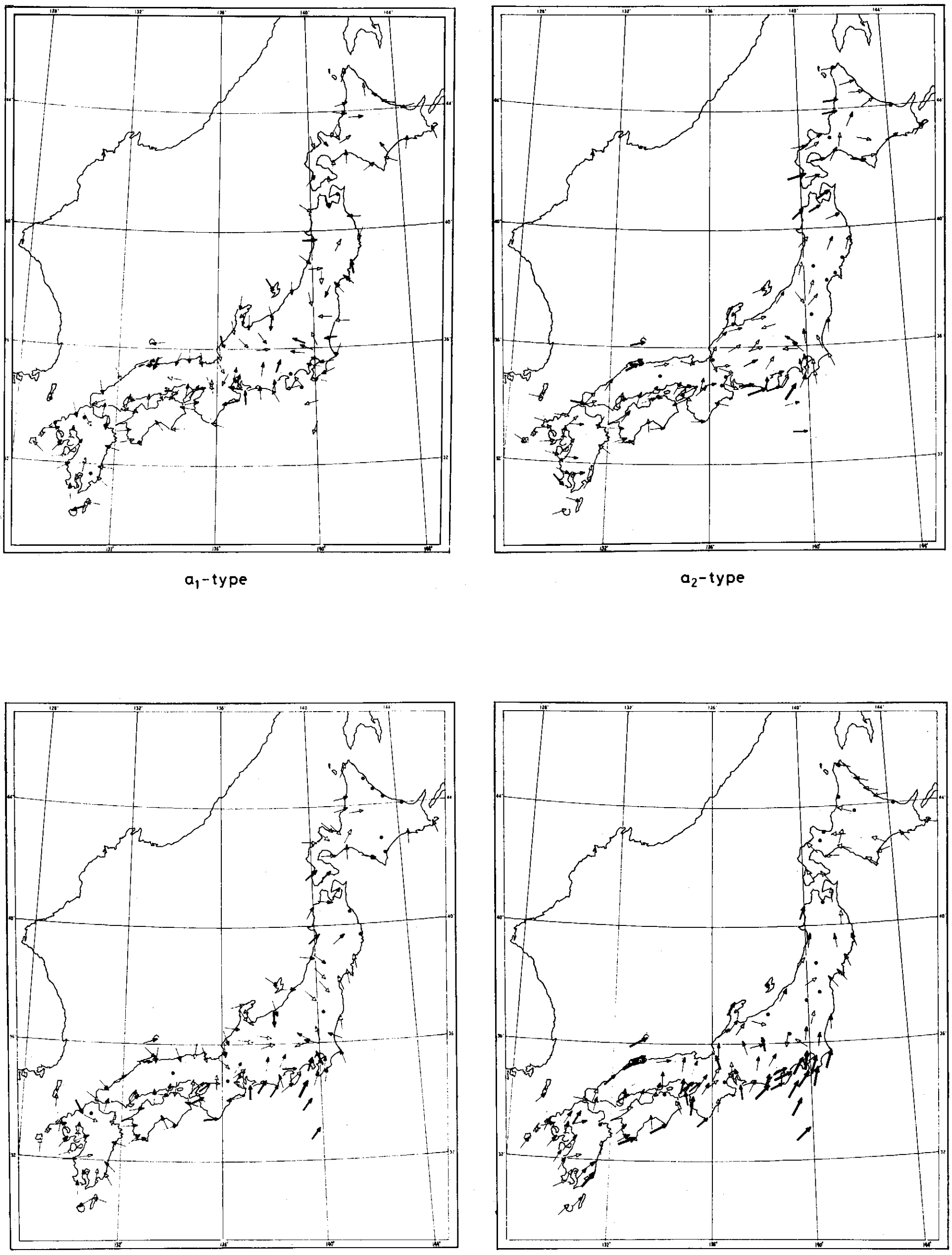
The representative surface wind distribution was expressed by the airflow pattern. For example, the prevailing wind direction was decided on each station and the streamline was drawn (Kawamura, 1966). The detailed surface wind distribution patterns were expressed by them. Also, the dynamic features of climate in the area were able to be clarified. But the kinetic characteristic which corresponded to the scale of cyclone or anticyclone was not clear. The synoptic climatological process of surface wind was not recognized, either. The meaning of the prevailing wind was not clear. Since the wind is vector, the resultant wind is the best to express the representative wind. In the macro-scale airflow patterns, the similar wind distributions are combined. So, the resultant wind is an effective expression (Fig. 4). Characteristics of surface wind distribution are as follows:

Southwesterly wind and sea breeze (a1-a4 type)

Wind direction is roughly south. But, it is different in each district. Local circulations develop.

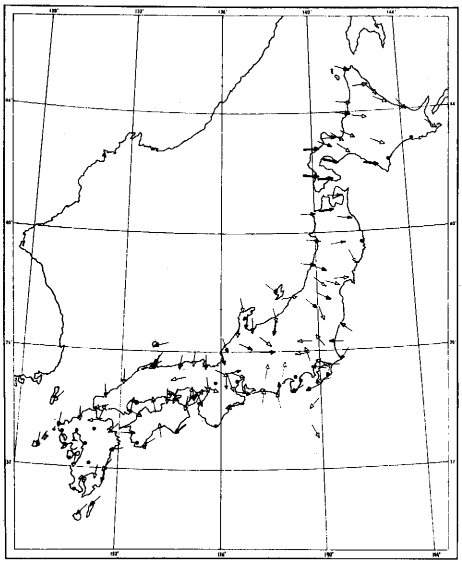
(a1) Sea breezes prevail all over the Japanese Islands. While southerly winds blow on the Pacific Ocean side, northerly winds blow on the Japan Sea side. On the Pacific Ocean side, winds blow almost at right angles to the coast line. But, a somewhat easterly component of wind is expressed over the whole area. Particularly, easterly winds blow into the inland on the Kanto District. Sea-breeze-like winds blow into the inland of the Chubu District. Winds from both the Japan Sea side and from the Pacific Ocean side converge around the Kanto Mountain District.

(a2) Southwesterly to west-southwesterly strong winds blow all over the Japanese Islands. In the Kanto District the wind direction changes counterclockwise from the windward to

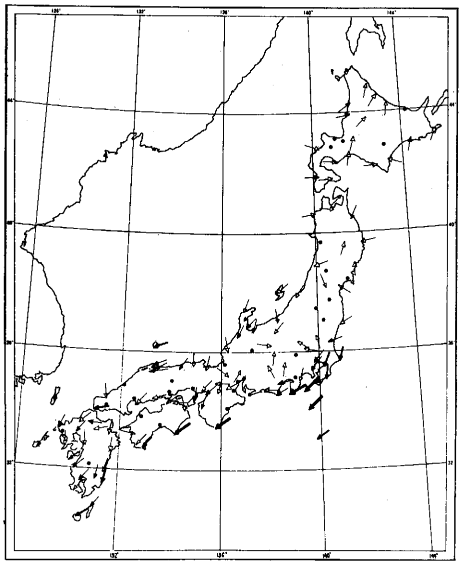


Wind Force · 0 ← 1 ← 2 ← 3 ← 4~

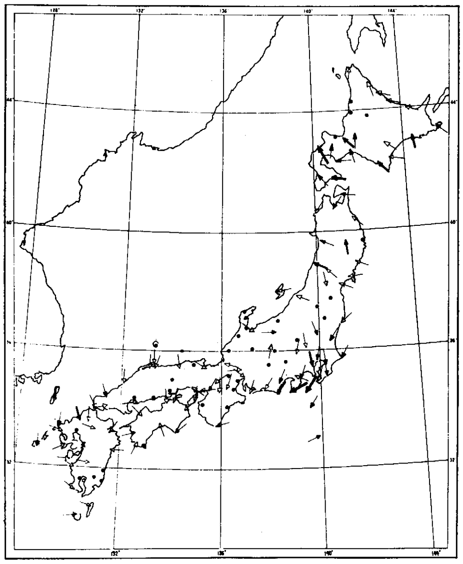
Fig. 4 The macro-scale airflow patterns of the Japanese Islands



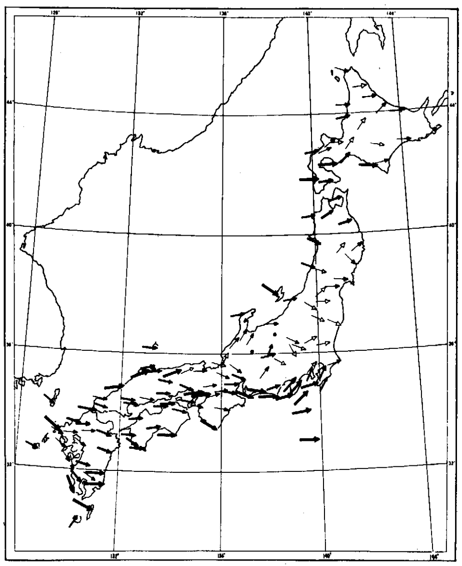
b_1-type



b_2-type

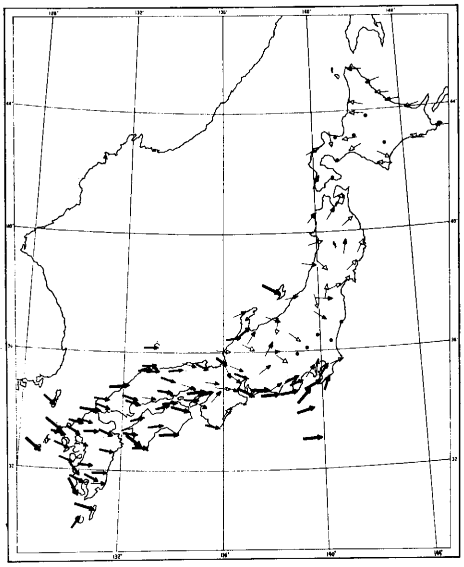


b_3-type

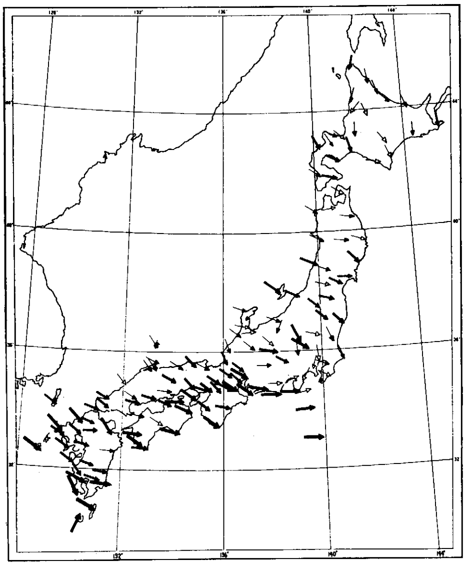


c_1-type

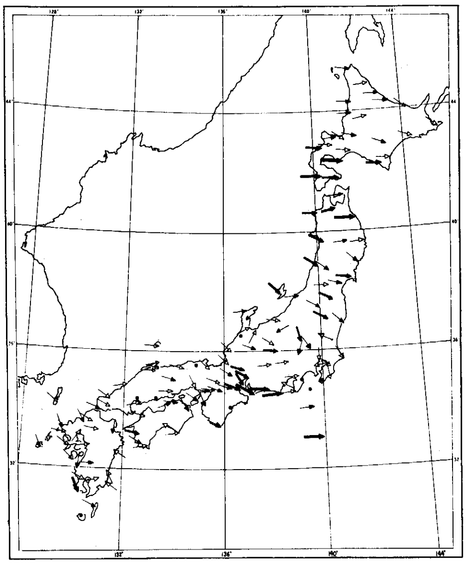
Fig. 4 (continued)



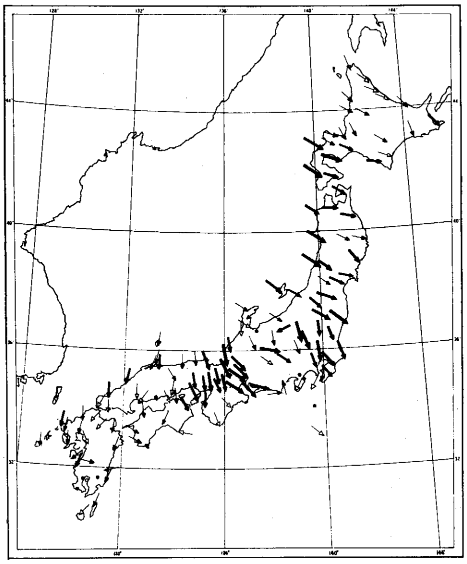
c₂-type



c₃-type



c₄-type



c₅-type

Fig. 4 (continued)

the leeward. They converge on the Kanto Mountain District.

(a3) Sea breezes prevail in the Japanese Islands except for the Pacific Ocean side of Hokkaido and the Tohoku District. On the Japan Sea side northerly winds blow such as the a1 type. On the Central and Southwestern Japan, a typical sea breezes blow. At many stations on the Pacific Ocean side the wind direction contains a westerly component. In the Kanto district, southerly winds blow. But inland, the wind direction changes counterclockwise, then it becomes an easterly wind. In the Chubu District, sea-breeze-like winds blow into the inland. That convergence zone is in the Kanto Mountain District. In the Tohoku District, the convergence zone is near the Pacific Ocean coast.

(a4) In Southwestern Japan, southwesterly winds blow. The surface wind distribution all over the Japanese Islands seems to be affected by cyclones. In the Tokai District and Southern Kanto District, the winds blow strongly.

Northeasterly wind (b1-b3 type)

Northeasterly winds blow particularly in Southwestern Japan. The wind system is a bit different between the north and south of the Japanese Islands.

(b1) In Northeastern Japan, roughly westerly winds blow. On the Japan Sea side of Southwestern Japan, roughly northerly winds blow. While on the Pacific Ocean side, easterly-winds-like sea breezes blow. They converge around the Kanto Mountain District.

(b2) In the west of the Chubu District, northeasterly winds blow. Strong winds blow especially on the Pacific Ocean coast. But, winds are very weak in the Tohoku District.

(b3) The south of southern part of the Tohoku District, northeasterly to northerly winds prevail. On the Pacific Ocean coast, somewhat strong winds blow on the eastern part, while gentle winds blow on the western part. In the north of the northern part of the Tohoku District southeasterly winds prevail.

Northwesterly wind (c1-c5 type)

All over the Japanese Islands roughly westerly strong winds blow.

(c1) Westerly winds blow all over the Japanese Islands. They are very strong, especially in Southwestern Japan. Small areas in which strong wind blows are dotted. They are related to topography. For example, this is clear in the Tokai District and the Straits of Tsugaru. These districts correspond with the side of mountain district or the middle of mountain districts.

(c2) In the south of the Tohoku District, westerly strong winds blow while in Hokkaido easterly winds blow.

(c3) All over the Japanese Islands northwesterly winds blow. Particularly in Southwestern Japan strong winds blow. In the inland of Chubu District, there are several stations at which strong winds blow.

(c4) Roughly westerly winds blow all over the Japanese Islands. However they are gentle except for Northeastern Japan. Merely on the Straits of Tsugaru and the Tokai District do strong winds blow.

(c5) The wind direction is roughly towards the north. In Northeastern Japan roughly northwesterly winds blow, while in Southwestern Japan roughly northerly winds blow. The winds are very strong in the north of the Kinki District. In the case of c1 to c4 type winds are strong in the Tokai District, while for the c5 type the winds are weak there. It may be a convergence zone. There are strong wind areas on the side of the mountain districts for the c5 type too.

Occurrence of the macro-scale airflow patterns

According to characteristics of surface wind distribution, each macro-scale airflow pattern seems to occur in different periods. The periods are significant characteristics of them. They correspond to the occurrence of pressure systems. The cyclone and anticyclone systems appear every year, though their frequency is different. So, it is considered that the macro-scale airflow patterns could be applied to other years.

To clarify the daily macro-scale airflow patterns in other years, discriminant analysis is used. It classifies the unknown sample according to the established type. In each cluster, it is considered that the variables are multi-dimensional normal distribution (Okuno *et al.*,

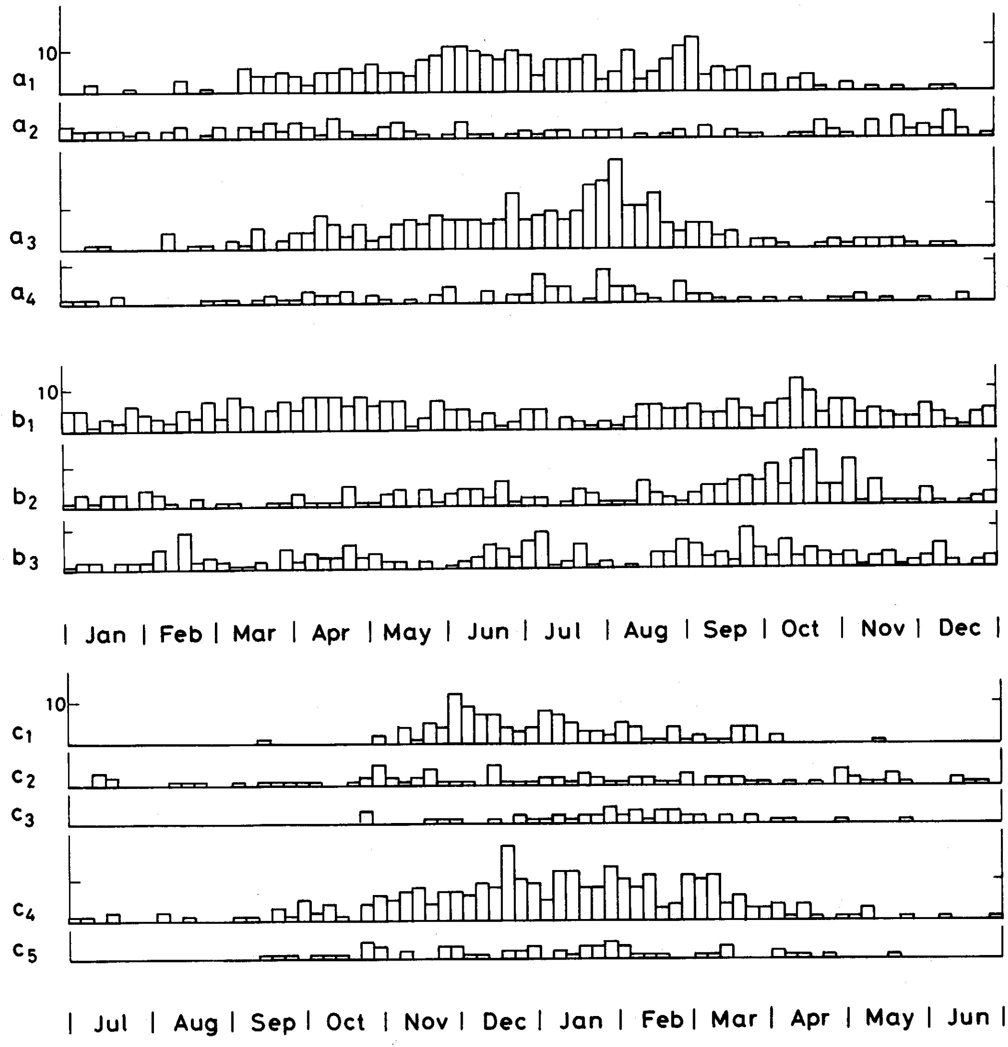


Fig. 5 Annual change of frequency of the macro-scale airflow patterns

1971). So, some statistical methods may be adopted in each cluster. For the variables, 10 stations out to the 137 stations are chosen (Fig. 1). The wind direction and the speed are represented using every 15 JST from 1968 to 1977.

By this discriminant analysis, the macro-scale airflow patterns of 10 years are clarified. The annual variation of each airflow pattern's frequency is exhibited (Fig. 5). The characteristics are as follows:

Summer wind (a1-a4 type)

The strong southwesterly wind which blows all over the Japanese Islands (a4) occurs from March. Its peak is in summer. Gentle sea breeze (a1) occurs especially in April and May. After them, developed sea breeze (a3) occurs especially in August.

Spring and autumn wind (b1-b3 type)

The northeasterly wind which blows all over the Japanese Islands (b3) occurs in June. The northeasterly wind which is clear only in Southern Japan (b2) occurs in autumn.

Winter wind (c1-c5 type)

The northwesterly wind which blows only on the south of the Tohoku District (c2) occurs in the whole year. The northwesterly wind whose direction is roughly toward south (c1 and c3) occurs frequently from late November on. Earlier than those the northwesterly wind whose direction is roughly toward north (c4 and c5) occurs frequently from October.

4. Concluding Remarks

In this work, an attempt was made to set up the macro-scale airflow patterns for the Japanese Islands. Therefore the area from Hokkaido to Kyushu was chosen. The 15 JST surface winds were classified by cluster analysis. Then 12 macro-scale airflow patterns were set up. Furthermore, they were classified into 3 principal types.

The representative surface wind distributions in the Japanese Islands were expressed in each pattern. They were classified into 3 types. According to the general wind direction, these are southwesterly wind or sea breeze, northeasterly wind, and northwesterly wind.

Based on the macro-scale airflow patterns, the daily patterns were clarified for ten years. The annual variations of the macro-scale airflow patterns were classified into 3 types. They are summer wind, spring or autumn wind, and winter wind distribution.

Furthermore, the macro-scale airflow is a typical pattern as compared to the monsoon. The monsoon is recognized as a typical wind which blows over the Japanese Islands. The details are omitted. But, it is clear that the macro-scale airflow patterns are influenced by the form of the Japanese Islands. Then, the climate of the Japanese Islands should be clarified, if the analysis is to be based on the macro-scale airflow patterns. Based on the macro-scale airflow patterns, the distribution of several climatic elements in the Japanese Islands will be expressed. These results will be presented on another occasion.

In addition, FACOM 230/45S of Tokyo Metropolitan University and HITAC 8800/8700 of Computer Center, Tokyo University were used in this study.

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