STUDIES OF JAPANESE CLIMATE BASED ON MACRO-SCALE AIRFLOW PATTERNS

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Abstract Cluster analysis is adopted to the airflow system of Japanese Islands and macro-scale airflow patterns are set up. In each macro-scale airflow pattern, pressure system and distribution of climatic element are characteristic. Adopting principal component analysis to distribution of climatic element, fundamental climatic conditions are expressed. By these conditions, land surface features and pressure system in major synoptic cimatological field are discussed. Further, influences of macro-scale airflow patterns to the yearly variation of air temperature and pecipitation are clarified.

1. Introduction

In synoptic climatology climate is expressed as the accumulation of daily weather. By this definition climate means most actual weather conditions and airflow patterns become an effective method of demonstrating climate.

In this study, surface synoptic wind distribution is called "airflow system". An airflow system is an intermediate factor between air pressure systems and other climatic elements. Distribution of climatic elements is altered by changes in airflow systems.

The type of airflow system presented in this study is called "airflow pattern". Airflow patterns represent the characteristics of a synoptic climatological field in a particular area. They are set up by wind direction at a particular station or by general wind direction determined by the strike of an isopleth.

Many studies have been made using airflow patterns as indices to express the distribution of climatic elements. For such a study of the Japanese Islands, meso-scale areas such as Hokkaido has been used (Jacobs, 1946). Distribution of precipitation (Maejima, 1954), wind (Numata, 1955) and weather (Shitara, 1966) have been clarified using other meso-scale area. In these studies, airflow patterns are set up by use of eight gradient wind directions.

However, airflow systems are usually influenced by large mountains and therefore do not usually fit precisely into one of these eight categories. In order to compensate for this, the airflow system is classified and that classification is used to determine the range of gradient wind direction which in turn sets up the airflow pattern (Kawamura, 1966).

In a macro-scale area such as the Japanese Islands, gradient wind direction is not usually regarded as being only one direction. Therefore, the Japanese Islands are divided into five districts and airflow patterns are set up for each (Maejima, 1954; Kawamura, 1964). Consequently, however, defining the distribution of climatic elements in the Japanese Islands requires a complicated technique of estimation based on the condition of appearance of airflow patterns at any given time.

Climate becomes clear from the accumulated distributions of climatic elements and reasonable airflow patterns must be set up to determine these (Tagami, 1981, 1982).

In the Japanese Islands, characteristic distributins of climatic elements appear seasonally. However, reasonable airflow patterns have not yet been determined. Consequently, climate cannot be grasped as an accumulation of these patterns. Instead, such problems as the airflow pattern a single gradient wind direction contains must be overcome. In order to do this it is best to set up macro-scale airflow patterns. Westerlies and northwesterly winds predominate over the Japanese Islands in winter. Southwesterly winds often blow in spring. The airflow system spreads over a macro-scale area in these cases, making it easier to deal with airflow systems for the entire archipelago rather than for each local area.

The airflow patterns set up on the airflow system in the Japanese Islands for this study are called "the macro-scale airflow patterns". Distribution of each climatic element in the Japanese Islands will be expressed by the macro-scale airflow patterns. Therefore, on the macro-scale airflow patterns, synoptic climatological characteristics will be clarified as a synthesis of climatological elements.

2. Setting Up Macro-Scale Airflow Patterns

Features of wind field in the Japanese Islands

In this study, first, the macro-scale airflow patterns are set up and then distributions of climatic elements are expressed. The "Magnetic Tape of Surface Weather" (1968-1977) recorded by Japan Meteorological Agency are used for most analysis. "Printed Weather Charts" (1973), "Aerological Data of Japan" (1973), "Monthly Weather Report" (1973) and "Climatic Table of Japan" (1941-1970) are also used.

Annual changes of pentad mean wind speed are different among the Japanese Islands. When cluster analysis with correlation coefficient as similarity is adopted to the standardized annual change of pentad mean wind speed, the following characteristics are found. The periods of maximum wind speed are as follows.

(1) from November to April for the coast of northern Japan and the Japan Sea side of southwestern Japan

(2) from March to May for the inland of northeastern Japan and the Pacific Ocean side of southwestern Japan

(3) from March to August (excluding June) for the East China Sea side of Kyushu

(4) from July to March for the southwestern islands

Types 1, 2 and 3 have their maximum wind speed season in winter or spring, while type 4 has its maximum wind speed season in autumn. The former covers Hokkaido to Kyushu and the latter covers the southwestern islands. The two present striking contrasts.

Airflow patterns in the Japanese Islands alter with the migration of cyclones and anticyclones. Such alteration corresponds in four day periods with the major cycle of wind speed (Hoven, 1957) and the weather cycle of "synoptic weather chart" scale. Also, when gradient wind directions on surface weather charts are the same, there are similar patterns of wind distribution in each season (Kawamura, 1970, 1977). This shows that airflow patterns are controlled mainly by migration of cyclones and anticyclones, but it is hardly influenced by annual changes. Also, individual airflow patterns may not be influenced by climatic fluctuation. Further, the airflow systems of 09:00 and 15:00 Japan Standard Time are almost the same (Kawamura, 1977). The airflow systems are similar to each other, in the day time with a maximum wind speed appearing at about 15:00 JST. 15:00 JST represents the daytime airflow pattern when air pressure incline is small. Moreover it represents the whole day airflow system when air pressure incline is large.

Comparison of subjective method and objective method

Wind is expressed by the vector of wind direction and wind speed. Airflow systems are sometimes expressed by the airflow line (Kawamura, 1966). By this operation, airflow system can be classified subjectively like other climatic element distribution.

Distribution of climatic element is also classified by statistical method. For example, "correlation method" is adopted to air pressure distribution on the eastern part of the U. S.A. (Lund, 1963), air pressure distribution around Japan (Nomoto and Tatsumi, 1972) and upper layer height distribution around Japan (Arai and Yajima, 1976). In the "correlation method", a correlation matrix is calculated on distribution maps. Next, numbers on the distribution map whose correlation coefficient with it is higher than the critical value are counted for every map. The map with the largest number is extracted as a pattern. Distribution maps whose correlation coefficient with the pattern are higher than the critical value are neglected. The same operation is repeated for the rest of distribution maps. However this "correlation method" is not sufficient because it needs trial classifications to decide the critical value. Furthermore, the relation among classified distribution maps is not shown.

Cluster analysis is adopted to the classification of a climatic area based on the monthly mean of climatic elements in Australia (McBoyel, 1971) and regional division by the prevailing wind directions over the mountains in Honshu, Japan (Kai, 1977). In general, such cluster analysis is used to define similarity between samples according to object and to combine pairs of samples with maximum similarity value into clusters.

Atmospheric phenomena usually continues in time and space. There are transition areas in airflow patterns. There are also shifting stages in the time series of airflow patterns. Airflow systems are classified subjectively on the preliminary selected conditions. However, many similarities of airflow patterns show up using objective methods. In this case airflow systems are classified without limitation of conditions.

Classification of airflow system by cluster analysis

The maximum wind speed term in the area from Hokkaido to Kyushu is the same; winter and spring. This area is the object of the establishment of the macro-scale airflow patterns. 137 stations which lie on plane were selected from the meteorological stations in the area (Figure 1). The data is obtained for ten years, from 1968 to 1977. To set up

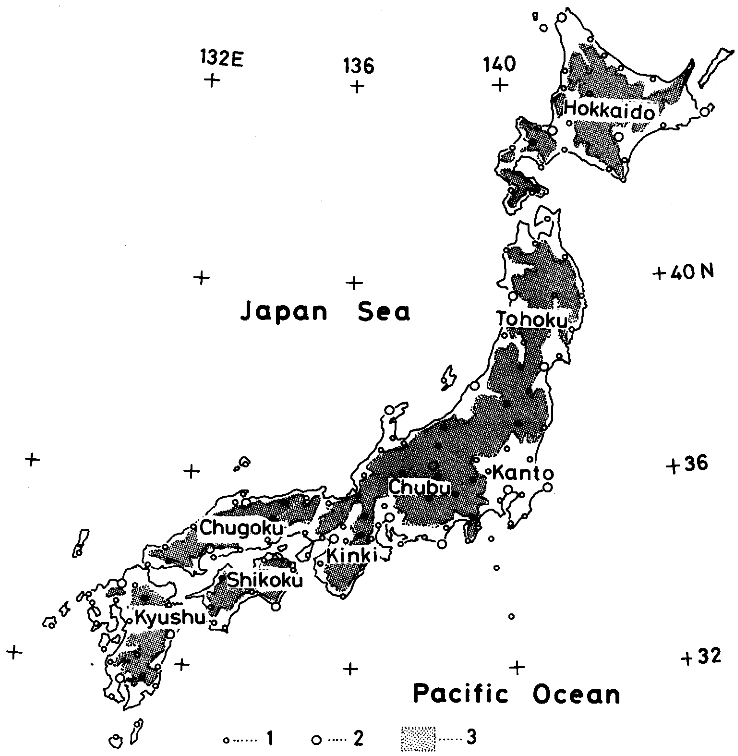


Figure 1 Locations of the meteorological stations
1. used only for cluster analysis
2. used also for discriminant analysis
3. above 200 m from m.s.l.

the macro-scale airflow petterns, the median year 1973 is analyzed. The airflow system for each day is represented by distribution of wind direction and speed at 15:00 JST. Cluster analysis is used to classify the airflow system because it does not limit the object and has little restriction on calculation. In cluster analysis, correlation coefficients and Euclidean distance are usually used for determining similarity. However, in using these for similarity, the characteristics of the local airflow system are emphasized. Because it is hoped that the characteristics of macro-scale airflow system will be expressed in this study, distance, which shows negative similarity between distribution maps, has been determined as the difference of winds between the same station on each map. Using "u" as the zonal component and "v" as the meridional component of wind which speed is precisely determined by its square root, distance of distribution map between day "a" and day "b", D_{ab}, is

$$D_{ab}=\frac{1}{137}\sum_{i=1}^{137}\sqrt{(u_{ai}-u_{bi})^2+(v_{ai}-v_{bi})^2}$$

Classification is carried out as follows:

(1) Distance between each distribution map is calculated according to the definition

above mentioned.
(2) Distribution maps which have minimal distance are combined as a cluster by weighted pair group analysis.
(3) Distances between new clusters and old ones are calculated again. Distance is based on the definition of recurring distance by group average method.
(2) and (3) are repeated until all of the distribution maps have been combined.

The process of clustering is expressed by dendrogram (Figure 2). Cluster will not be combined, in spite of increases in distance, where distance index value is 2.2. In this case, the variance should be larger between, rather than within, the clusters themselves. The twelve clusters which have more than ten days at distance index 2.2 are chosen to classify airflow system. These clusters are made into three principal clusters.

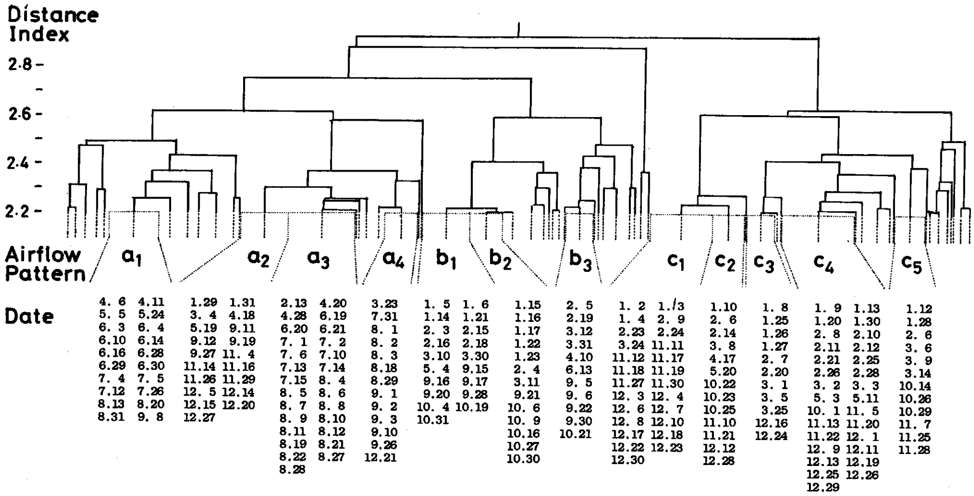


Figure 2 Dendrogram of the cluster analysis on surface wind in the Japanese Islands
Data is in 1973, dendrogram is neglected under distance index 2.2

Characteristics of macro-scale airflow patterns in the Japanese Islands

The airlfow systems in the Japanese Islands which are classified by cluster analysis are made into macro-scale airflow patterns. They are expressed by the resultant wind of each cluster. Surface wind distribution in Japan is clarified using the airflow pattern for each local area (Kawamura, 1963, 1977). This distribution also enables analysis of the dynamics of climate. Another point cleared by resultant wind distribution in the Japanese Islands is that the airflow patterns change according to the migration of cyclones and anticyclones. The macro-scale airflow patterns are broken down into *a*, *b* and *c* types. Members of each category are further called a_1-a_4, b_1-b_3, c_1-c_5 type with characteristics as follows (Figure 3).

a-type: Wind direction is roughly south. Local circulations develop when general wind is weak.

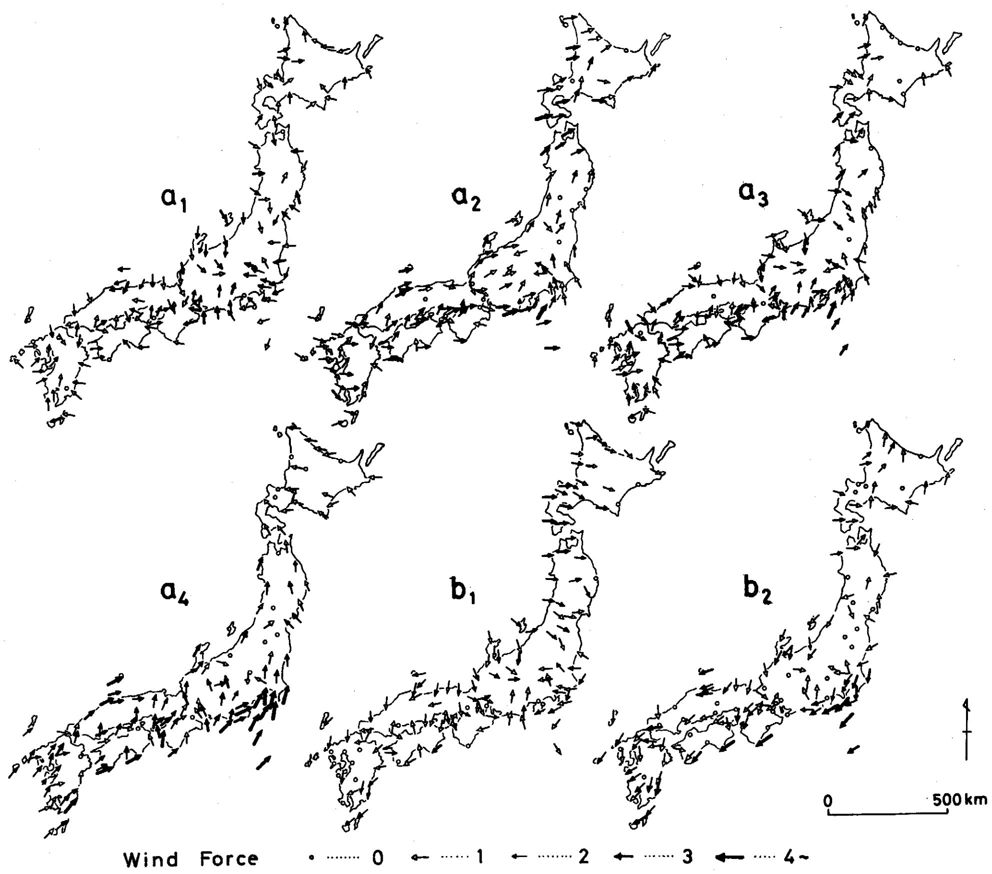


Figure 3 The macro-scale airflow patterns in the Japanese Islands (expressed by resultant wind)

a_1: Sea breezes prevail on the coast. While southerly winds blow on the Pacific Ocean side, northerly winds blow on the Japan Sea side.

a_2: Southwesterly to west-southwesterly strong winds blow. Wind is intensely deformed over central Japan. Westerly winds blow in the Tokai district and around the Chubu Mountain area their direction changes to counter-clockwise. Southerly winds blow in Kanto District.

a_3: Sea breezes prevail south of the Tohoku district. Sea breezes also blow intensely on the Southern Coast (west of the Boso Peninsula on the Pacific Ocean side). Their directions are roughly southwesterly.

a_4: Southwesterly strong winds blow. Roughly westerly winds in southwestern Japan change their direction counterclockwise and easterly winds blow in Hokkaido.

b type: Northeasterly winds distinctive to southwestern Japan blow. Sometimes westerly winds blow in northeastern Japan.

b_1: Easterly winds blow on the Pacific Ocean side; northearly or westerly winds blow

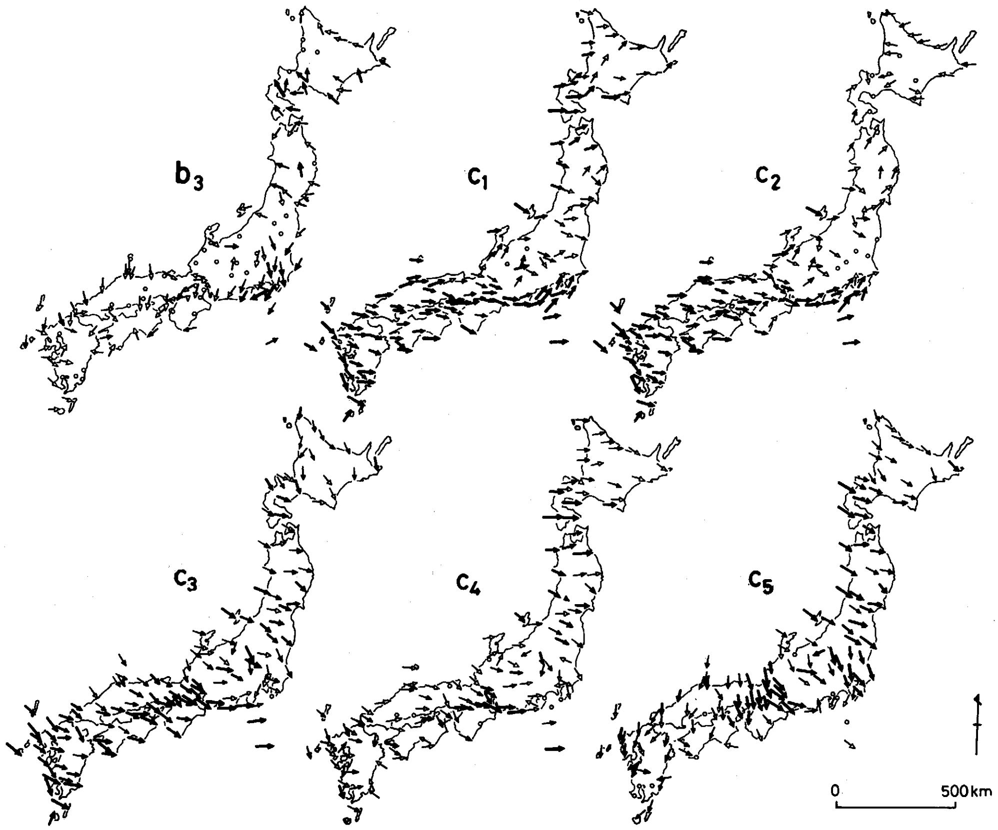


Figure 3 *continued*

on the Japan Sea side.

b$_2$: Northeasterly winds blow in southwestern Japan. Strong winds prevail particularly on the Southern Coast while southwesterly winds blow in northeastern Japan. Between these areas, in the southern part of the Tohoku District, winds are usually weak.

b$_3$: Easterly winds blow in northeastern Japan, the Kinki District and the eastern part of Chugoku, Shikoku District. Wind directins are quite different when bounded by the southern part of the Tohoku District. Northearly winds blow in the southern area and southerly winds blow in the north.

c type: Westerly strong winds blow, although locally deformed when influenced by Chubu Mountain Area.

c$_1$: Westerly strong winds blow, becoming especially severe in southwestern Japan. Winds are intensified at channels and wind gaps between mountains.

c$_2$: Westerly strong winds blow in the western part of the Kanto District. Wind directions change to south in the northern part of the Tohoku District. Easterly winds blow in Hokkaido.

c$_3$: Northwesterly strong winds blow, particularly in southwestern Japan. Northerly winds blow in Hokkaido.

c_4: Westerly strong winds blow, stronger in northeastern Japan than southwestern Japan. Winds are strong, particularly around the Strait of Tsugaru.

c_5: Northwesterly strong winds blow in northeastern Japan. Northearly winds blow in southwestern Japan, being particularly strong on both sides of the Chubu Mountain area, the Kanto District and the Kinki District.

3. Macro-Scale Airlfow Patterns and the Synoptic Climatological Field around the Japanese Islands

Annual change in frequency for macro-scale airflow patterns

The study of airflow patterns, the relation between wind direction and weather, evolved within early synoptic climatology (Barry and Perry, 1973). Airflow patterns have been recognized as showing macro-scale weather in the same way Grosswetter does (Gressel, 1952; Barry, 1960). Further, distributions of climatic elements have been expressed using airflow patterns as an index (Maejima, 1954; Kawamura, 1961). These studies were carried out using the basic characteristics; the annually changing frequency of airflow pattern which alters with the synoptic climatological field.

Macro-scale airflow patterns change; however, not in numbers sufficient to make clear the frequency of these changes. Consequently, macro-scale airflow patterns from 1968 to 1977 must be clarified using discriminant analysis from which results, pentad mean frequencies of macro-scale airflow patterns are calculated. Cluster analysis using similarity of correlaton coefficient is adopted and pentads whose frequencies are alike are classified together. The results show the wind seasons in the Japanese Islands (Figure

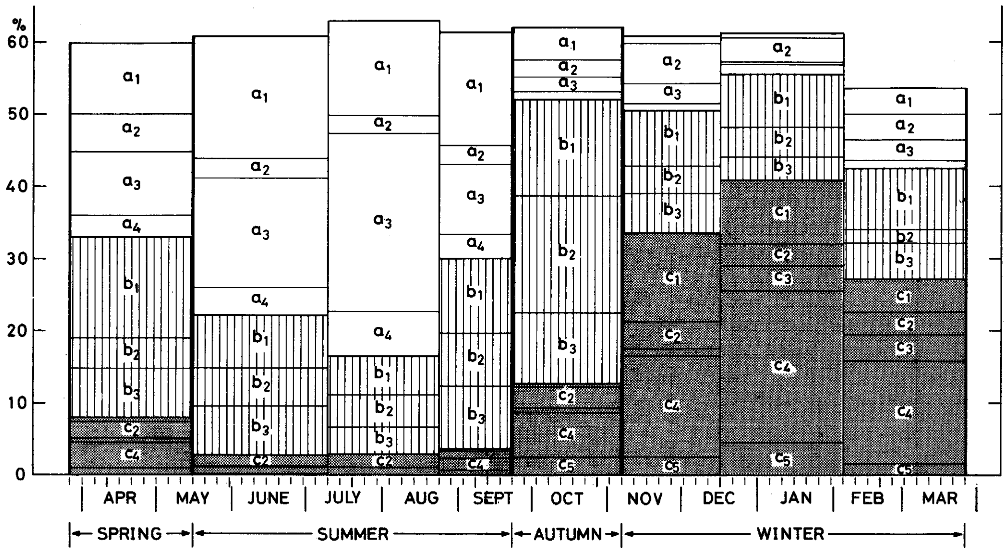


Figure 4 Seasonal change in frequency of macro-cale airflow patterns
Summer and winter are divided into early, mid and late stages

4). *A*-type prevails in "summer", *b*-type prevails in "spring" and "autumn" and *c*-type prevails in "winter".

Three rainy seasons and three intermediate seasons have already been clarified according to the singularity which appears by calendar day mean of climatic elements (Maejima, 1967). Natural seasons have been set up according to the calendar day frequency of pressure patterns, (Yoshino and Kai, 1977). The mid-summer of these natural seasons coincides with the mid-summer of the wind seasons. However, the "winter" of the two system differs greatly. Winter as determined by macro-scale airflow patterns begins earlier and ends later than winter as classified by others.

Features of surface pressure field and upper level wind field

The macro-scale airflow patterns correspond well to the patterns of synoptic climatological field. This characteristic is clear from the migration of cyclones and anticyclones. When a macro-scale airflow pattern appears, the center position of the cyclone or anticyclone at 09:00 and 21:00 JST are determined and the middle positions of 09:00 and 21:00 JST are plotted (Figure 5). They are regarded as the center position of the cyclone or anticyclone at 15:00 JST.

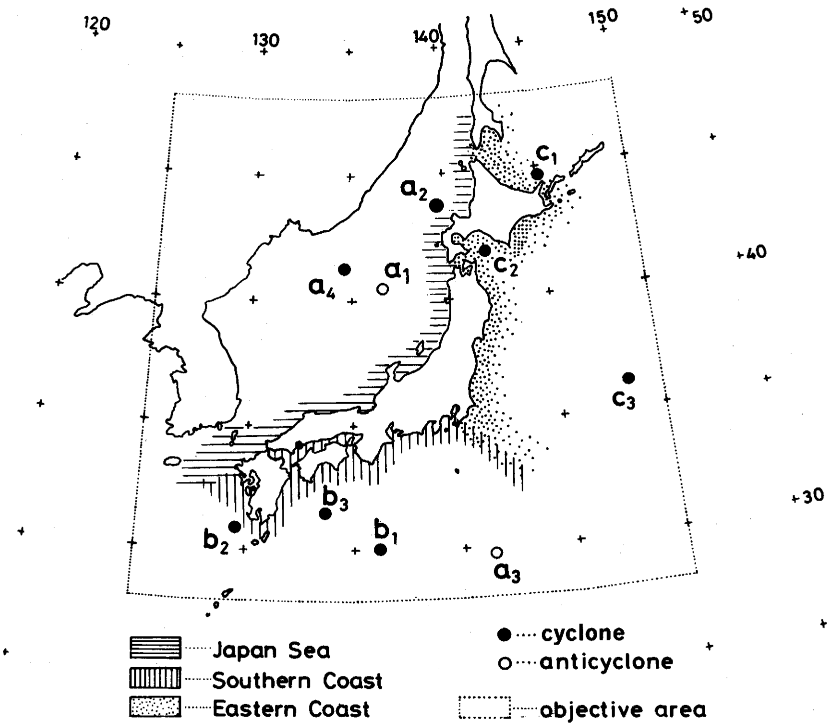


Figure 5 The area in which cyclones or anticyclones lie for each airflow pattern Each center is expressed as the average position of the concerned cyclone and/or anticyclone around the Japanese Islands

Center positions of cyclones are different for each macro-scale airflow pattern type. For *a*-type, they are in the Japan Sea; for *b*-type, on the Southern Coast; and for *c*-type, on the Eastern Coast (north of the Boso Peninsula on the Pacific Ocean side and the Okhotsk Sea side).

There are some differences between each macro-scale airflow pattern for 850 mb level winds in the Japanese Islands (Figure 6). Westerly winds with speeds under 10 m/s blow in a_1 and a_3 types. Southwesterly winds with speeds of over 10 m/s blow along the strike of the Japanese Islands in a_2 and a_4 types.

Winds of under 10 m/s are *b*-type. Westerlies are weakened by easterlies which blow along the southern part of a northern anticyclone and other easterlies which blow along the northern part of southern cyclone.

Winds of over 10 m/s are *c*-type. The wind force is weakened on the windward or leeward sides of mountains, while being intensified beside mountains. Northwesterly winds blow through mountain gaps at right angles to the strike of Japanese Islands. For example, they blow in the Strait of Tsugaru, the gap from Sakata to Sendai, Sekigahara and the Strait of Kanmon.

Synoptic climatological characteristics of macro-scale airflow patterns

The main characteristics of the frequency and pressure field for each macro-scale airflow pattern are as follows.

a type: This type appears mainly in the summer. In this type, cyclones are located in the Japan Sea. A_1 type appears from February and prevails in April and May. A_3 type prevails in August. A_4 type appears from March with its maximum frequency in August. A_2 type appears throughout the year. As a_1 type appears, travelling anticyclones reach the Japanese Islands and as a_3 type appears, Pacific Anticyclones spread over the Japanese Islands. As a_2 type appears, cyclones are located on northern part of Japan Sea and as a_4 type appears, cyclones are located on central part of Japan Sea.

b type: This type appears throughout the year, with greatest frequency in spring and autumn. As *b* type appears, the center of cyclone is located on the Southern Coast and the center of anticyclone is located on the north of the Japanese Islands. B_1 type often appears in spring and autumn while b_2 type appears most concentratedly in autumn. B_3 type often appears in spring and autumn and also appears in June. In June a_3 type begins to prevail, while a_1 type disappears. Centers of anticyclones are located on the Japan Sea as b_1 type appears, in northeastern Japan as b_2 type appears and on the Eastern Coast on b_3 type appears.

c type: *C* types appear most concentratedly in winter. As *c* types appear, anticyclones are located over the continent and cyclones are located on the Eastern Coast. C_2 type and c_5 type appear throughout the year while c_1 type appears mainly in early winter and c_3 and c_4 types appear mainly in late winter. Cyclones are located east of the Strait of Soya as c_1 type appears and east of the Strait of Tsugaru as c_2 type appears. Because of these dispositions of cyclone and anticyclone, strong winds blow particularly in southwestern Japan. For c_3 type, cyclones are located east of the Boso Peninsula and strong winds blow all over the Japanese Islands. Cyclones are located in the Okhotsk Sea as c_4 type appears and are located in the far east of the Sanriku District

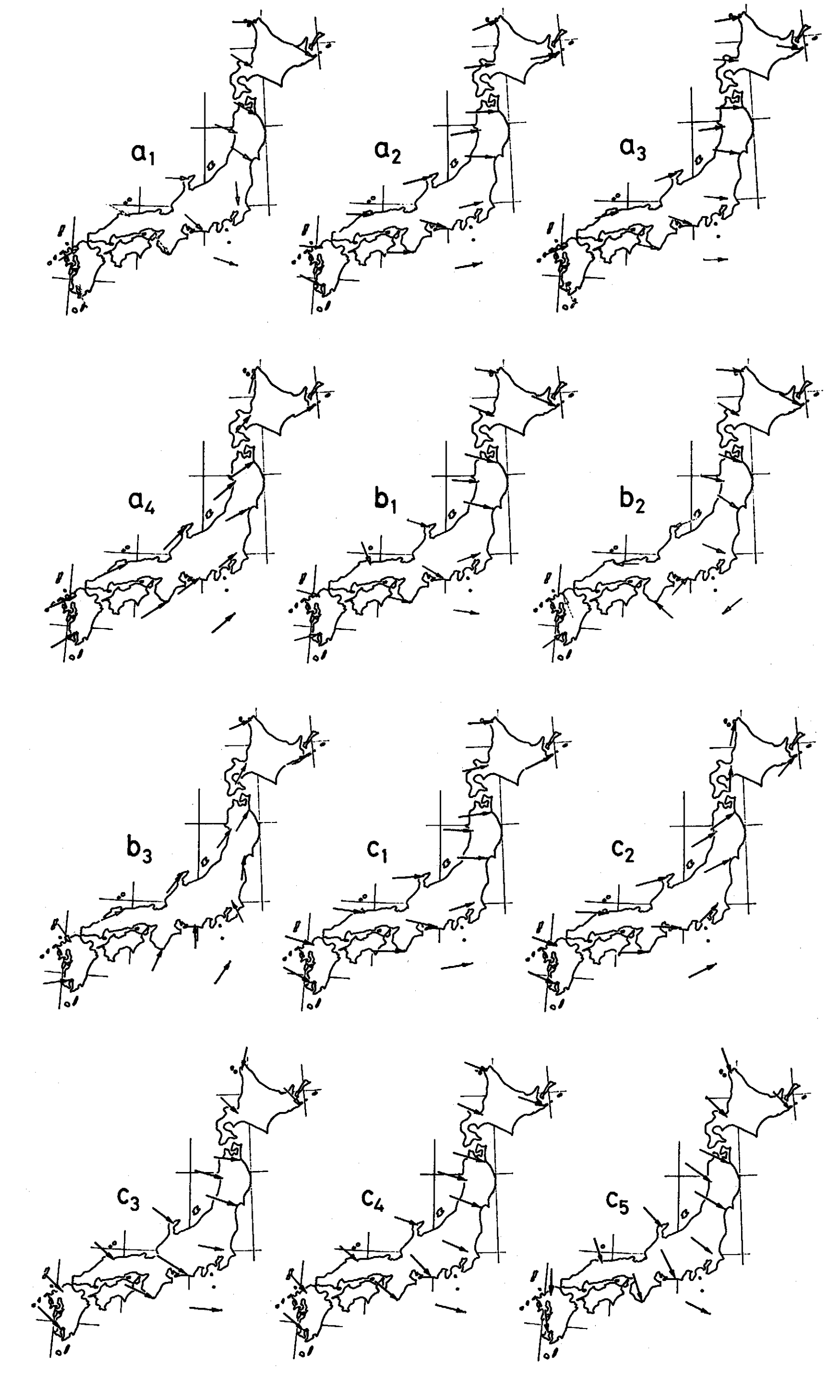


Figure 6 Upper (850mb) wind distribution for each macro-scale airflow pattern (expressed by resultant wind of 09 : 00 JST)

as c_5 type appears. Anticyclones expand from the continent to the Japanese Islands as both c_4 and c_5 types appear. Under these conditions, strong winds blow in northeastern Japan. Pressure systems are biased toward the west as c_1 and c_2 types appear, while they are biased toward the east as c_3, c_4 and c_5 types appear.

Comparison of macro-scale airflow patterns and monsoons around the Japanese Islands

Macro-scale airflow patterns show distinctive annual change of frequency which is connected with pressure systems as stated above. These characteristics are recongnized by comparing macro-scale airflow patterns and monsoons which have been clarified using synoptic climatology. A_1 type is similar to the temperate monsoon (early summer monsoon) and a_3 type is similar to the subtropical monsoon (mid summer monsoon). A temperate monsoon is a Southerly which blows when east-high and west-low pressure patterns appear. A subtropical monsoon is also a Southerly. However, it blows when south-high and north-low pressure patterns appear (Kurashima, 1959, 1968).

Northeasterly monsoons blow in summer in the Maritime Provinces (Kurashima, 1959). *B* types correspond with the northeasterly monsoon when the monsoon is biased toward the south. B_3 type seems to correspond with Northeasterly Airflow (Hokuto Kiryu) during baiu season.

C type is smilar to the winter monsoon which consists of northeasterly airflow and a northwesterly monsoon. Northeasterly airflow corresponds to the winter pressure system which is biased toward the north. Northwesterly monsoon corresponds to the winter pressure system which is biased toward the south (Kurashima, 1959). On the other hand, the bias of a pressure system toward the east or the west causes the major differences among the *c* types.

4. Examination of Macro-Scale Airflow Patterns as an Indicator of the Synoptic Climatological Field

Objective methods to examine the criteria in synoptic climatological analysis

If appearance of the macro-scale airflow pattern and the latent pattern in climatic element distribution corresponds, then climatic element distributions which are classified by macro-scale airflow patterns each show different patterns. In the opposite order, when the differences among each climatic element distribution classified by macro-scale airflow patterns are pointed out, the macro-scale airflow patterns are proven undoubtedly effective indicators of the synoptic climatological field. These differences may be evaluated objectively using some statistical methods.

In one method, the hypothesis that the original group of climatic element values of each classification criteria is different is set up. F-test and t-test are adopted for this hypothesis. When this hypothesis is accepted, there is a significant difference of climatic element value between two criterion (Hohgetsu, 1979).

Other methods use a discriminant analysis. First the climatic element distribution is classified using the criteria. Then discriminant function which divides the classifications most efficiently is calculated. If each distribution is discriminated from the original group by a discriminant function, it is clear that climatic element distribution is different for each criteria (Brinkmann, 1970).

Examination of macro-scale airflow patterns by discriminant analysis

The significance of macro-scale airflow patterns on synoptic climatology is examined by discriminant analysis. Distribution of climatic element is classified by macro-scale airflow patterns and discriminant analysis is adopted to the combination of two groups for each time. If each distribution is discriminated exactly from the original group on every combination of two groups, then the distribution of climatic element is different for each. At the same time, it is proven that macro-scale airflow patterns are significant indicators of the synoptic climatological field. This process of discriminant analysis is adopted to ten climatic elements including air pressure, temperature, precipitation and others. Twenty randomly located meteorological stations are chosen (Figure 1) and macro-scale airflow patterns are set up for 1973. The value of some of the ten climatic elements are measured at 15:00 JST, while certain elements including precipitation and evaporation are measured by diurnal values.

The result of this value representation is that climatic element distributions are almost exactly discriminated (Table 1). For sea level pressure, the discrimination ratio is higher than 90% on every macro-scale airflow pattern. Elements which are observed at 15:00 JST: air temperature, water vapour pressure, relative humidity, wind speed and cloud amount are closely discriminated, too. However, the discrimination ratios for some elements are rather low. These elements are those which are represented by diurnal values such as evaporation and precipitation, neglecting sunshine duration and global solar radiation which are restricted by daytime weather conditions. These results show that distributions of climatic elements which are classified by macro-scale airflow patterns differ. Accordingly the significance of macro-scale airflow patterns as an indicator becomes clear.

Table 1 Discriminate ratio of the climatic element distribution (%)

air flow pattern (sample)	a_1 20	a_2 19	a_3 27	a_4 13	b_1 19	b_2 13	b_3 11	c_1 25	c_2 13	c_3 11	c_4 29	c_5 12
sea level pressure	90	100	100	100	95	100	100	96	100	100	97	92
air temperature	100	89	93	100	84	100	100	92	92	91	79	67
water vapour pressure	95	63	70	92	74	100	100	72	92	100	72	100
relative humidity	90	84	96	100	89	92	100	80	92	100	62	92
wind speed	75	89	74	100	95	92	91	88	100	100	93	100
cloud amount	80	68	70	100	74	92	91	88	100	82	66	75
duration of sunshine	90	74	70	92	74	85	100	88	100	91	69	92
global solar radiation	85	79	89	100	79	100	100	96	92	82	69	92
evaporation	55	37	63	69	47	46	73	52	69	55	45	83
precipitation	85	53	63	85	58	46	82	80	69	82	59	67

5. Climatic Element Distribution in the Macro-Scale Airflow Patterns

Principal features of climatic element distribution

Distribution of climatic elements show similarity within macro-scale airflow patterns. Therefore, the features of climatic element distribution can be seen by each mean map. Mean maps show 10 climatic elements in 12 macro-scale airflow patterns.

The principal features of climatic element distribution are as follows;

(1) Influence of great mountains. This characteristic is clear particularly for sea level pressure.

(2) Differences between northeastern Japan and southwestern Japan. This characteristic is clear for air temperature and water vapour pressure; It also appears for sunshine duration. In the *b*-type, this characteristic also appears for precipitation and relative humidity.

(3) Differences between the Pacific Ocean side and the Japan Sea side. The dividing mountains show a strong affect which appears regarding cloud amount, precipitation and relative humidity in the *c*-type.

(4) Differences between sea coast and inland. This is clear for wind speed and reltive humidity in the *a*-type. It also appears for air temperature in the *a*-type.

There are similar characteristics among the distributions of the climatic elements. Three major climatic elements; air pressure, air temperature and precipitation can almost represent all the climatic elements. The principal features of climatic element distribution for each macro-scale airflow pattern will be described focusing on these 3 elements.

Sea level pressure

There is a cyclone over the Japan Sea for *a*-type, while there is a cyclone over the Southern Coast for *b*-type and is a cyclone over the Eastern Coast for *c*-type (see 3.3). Sea level pressure patterns in the Japanese Islands relate strongly to these synoptic climatological fields. Sometimes the isobars run parallel to the strike of the Japanese Islands. Sea level pressure patterns also relate to the dividing mountains and the local mountains (Figure 7).

For a_1 type and a_3 type, the Japanese Islands are covered by anticyclones. Air pressure falls over the inlands. In the Chubu (central) District, local depression develops and air pressure is about 5 mb lower inland than at the sea shore. For a_2 type and a_4 type, air pressure is higher on the Southern Coast than on the Japan Sea side.

For *b* type, air pressure is higher in the north than in the south. Sometimes local depression appears. Air pressure is higher on the Japan Sea side for b_1 type, in the Tohoku District for b_2 type and in the eastern part of Hokkaido for b_3 type.

For *c* type, air pressure is higher in southwestern Japan than in northeastern Japan. In the Kanto and Tokai Districts, on the leeward side of the Chubu Mountains, local low pressure areas appear. In the Hokuriku District, on the windward side of the Chubu Mountains, air pressure rises locally and the pressure gradient is very steep. Air pressure falls in the eastern part of Hokkaido for c_1 type, in the southern part of Hokkaido for c_2 type and in the southeastern part of Hokkaido for c_3 type. For all these types, air

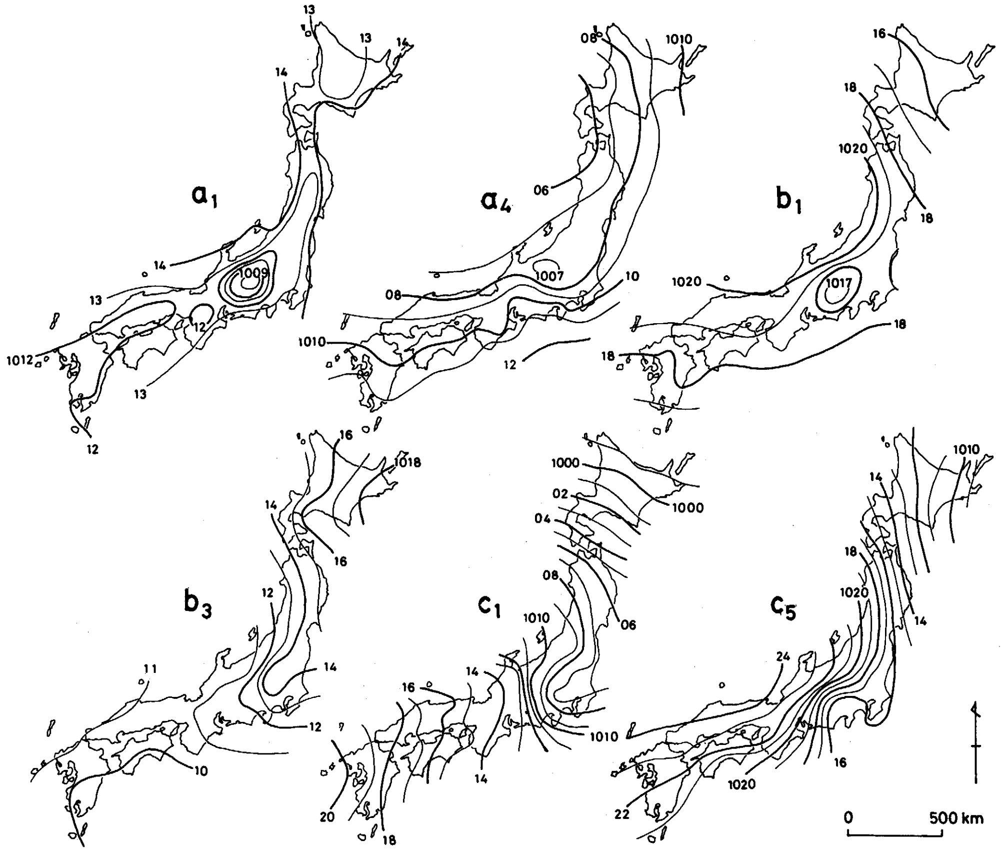


Figure 7 Distribution of sea level pressure for macro-scale airflow patterns (mb) (expressed by mean map)

pressure rises in the western part of Kyushu. Also air pressure is depressed locally in the Kanto District for these types. For c_4 and c_5 types, air pressure is lower on the Eastern Coast and higher on the Japan Sea side of southwestern Japan. The area where air pressure rises is biased northward for c_4 and c_5 types compared to c_1, c_2 and c_3 types. Around Suruga Bay, air pressure falls locally for c_4 and c_5 types. This pressure depressed area is biased southward compared to c_1, c_2 and c_3 types.

Air temperature

There is a distinctive difference in air temperature distribution between northern Japan and southern Japan. There is also a difference between inland and coastal regions. Accordingly high temperature areas appear inland (Figure 8).

For a_1 and a_3 types, local high temperature areas appear inland. Inland temperature values are mostly the same throughout southern Japan. It is also hot inland in northern Japan, which shows that there is little difference between inland northern Japan and inland southern Japan. In northeastern Japan the Eastern Coast is cool and the

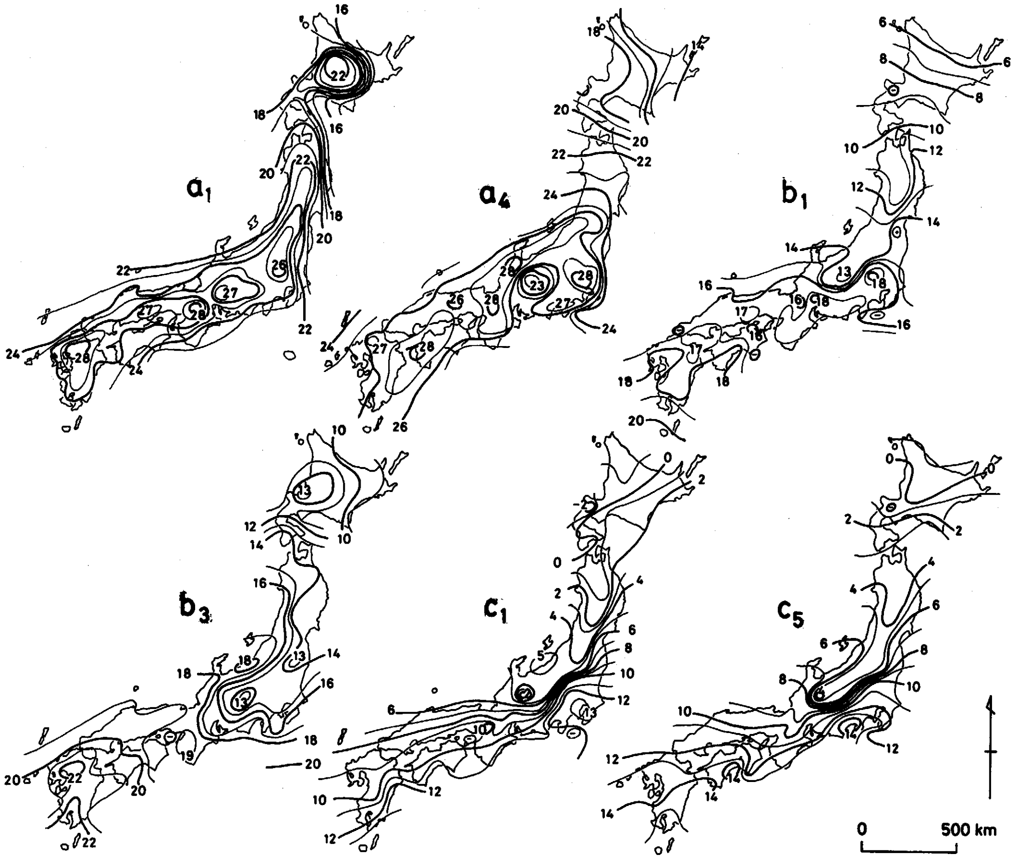


Figure 8 Distribution of air temperature for macro-scale airflow patterns (°C) (expressed by mean map)

temperature gradient between inland and coast is very steep. On the other hand, the inland high temperature area is indistinct for a_2 and a_4 types. Local warm areas appear in the Hokuriku District, leeward of the Chubu Mountains for a_4 type.

For *b* type, it is cool throughout southwestern Japan. On the other hand, in northeastern Japan it is cool on the windward side of dividing mountains and warm on the leeward side. For b_1 type the windward cool area is the Japan Sea side while it is the Pacific Ocean side for b_3 type. Only for b_2 type does temperature not differ between the Pacific Ocean side and the Japan Sea side in northeastern Japan.

For *c* type, in the south of the Tohoku District, it is cooler on the Japan Sea side than on the Pacific Ocean side. The temperature gradient is steepest around the Kanto Mountains and the Akaishi Mountain Range. On the leeward side of large mountains, local warm areas appear. For c_1, c_2 and c_3 types, the warm area of the leeward lies in the Kanto District. The temperature in the Kanto District is 10°C higher than in the Hokuriku District windward area. For c_4 and c_5 types, the warm area leeward of the Chubu Mountains lines on Suruga Bay.

Precipitation

When airflow systems change daily, distribution of daily amounts of precipitation does not always relate to macro-scale airflow patterns. To offset the influence of variations in macro-scale airflow patterns, when the same patterns continue for three days only the central day is accepted. Characteristics of precipitation distribution are not sufficiently expressed by the daily amount of precipitation because this varies greatly. Instead precipitation distribution is expressed by compiling statistics on precipitation of more than 0.5 mm and of more than 5 mm falling in 24-hour period. The influence of dividing mountains distinctively appears on the distributions of frequencies (Figure 9).

For a_1 and a_3 types, there is little precipitation except inland from the Chubu District to the Tohoku District. The inland precipitation area is in central Japan for a_1 type and in the northern part of the Kanto District for a_3 type.

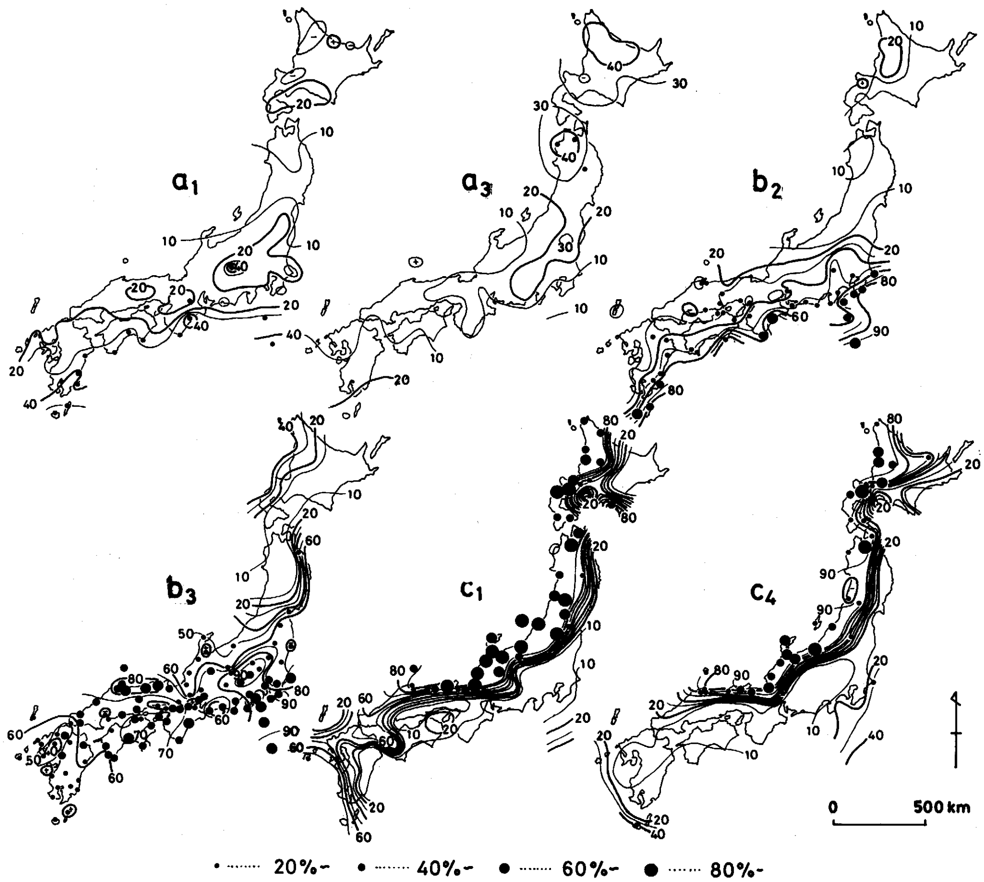


Figure 9 Distribution of precipitation frequency for macro-scale airflow patterns (%)
(expressed by mean map)
Isopleths denote whole rain (0.5mm/day∼)
Dots denote heavy rain (5mm/day∼)

For b_2 and b_3 types, precipitation frequency is greatest in southwestern Japan. Frequency of precipitation is very large on the windward side of mountains, east of the Kii Mountains and east of the Shikoku Mountains, for b_2 type. Frequency of precipitation of more than 5 mm/day is greatest on the Southern Coast and in the Sanin District.

For c_1 and c_4 types, frequency of precipitation is higher on the Japan Sea side than on the Pacific Ocean side. Precipitation of more than 5 mm/day appears only in the north of the eastern part of the Sanin District on the Japan Sea side. The gradient of precipitation frequency is steep along the dividing mountains. Comparing c_1 type and c_4 type, the precipitation area is larger for c_1 type and expands to the Pacific Ocean side and the East China Sea side. For c_1 type, precipitation appears on the western side of the Hidaka Mountain Range and the western part of Shikoku as well.

6. Fundamental Conditions of Climate and those Factors in the Japanese Islands

Principal component analysis about climatic condition

As mentioned on chapter 5, the features of climatic element distribution are as follows.

(1) influence of great mountains
(2) differences between northeastern Japan and southwestern Japan
(3) differences between the Pacific Ocean side and the Japan Sea side
(4) differences between inland and sea coast

By these understandings of climatic element distribution, the fundamental condition of climate and factors which control the synoptic climatological process can be clarified.

Climate and its factors in Japan have been discussed in terms of synoptic climatology already. For example, the strike of the Japanese Islands which is vertical to northwestern monsoon and southeastern monsoon is carried out. The strike is considered a significant factor to the Japanese climate (Komabayashi and Nakamura, 1976). Former synoptic climatological understandings of the Japanese Islands were usually based on the analysis of upper scale circulation and air mass. As described in chapters 4 and 5, climatic element distribution is similar for each macro-scale airflow pattern. They may be affected by the same climatic factors. For example, the strike of the Japanese Islands turns in central Japan. This fact is considered a climatic factors. This factor may be related to the fact that cyclones on the Southern Coast move eastward and reach the east of the Boso Peninsula, before winter-type precipitation begins. Also, according to this factor, macro-scale airflow patterns are classified as *b*-type when the cyclone is on the Southern Coast and *c*-type when the cyclone is on the Eastern Coast.

Statistical methods are necessary to make the fundamental conditions and controlling factors of Japanese climate clear. A synoptic climatological field which is expressed by climatic elements is usually analyzed. Needless to say climate is not constructed only by climatic elements, although analysis of climatic elements is the most useful process in the statistical method. Principal component analysis describes characteristics of individuals expressed by variables. In this study, the synoptic climatological field is expressed by climatic elements and principal component analysis is adopted to it. By this analysis, fundamentals of climate and factors pertaining to them became clear.

Principal component analysis is adopted to the synoptic climatological field in the Japanese Islands by following process.

(1) The observed value of 137 stations is used (Figure 10). These values, taken in 1973, are sea level pressure, air temperature, water vapour pressure, relative humidity, wind speed, cloud amount, sunshine duration and precipitation. The mean deviation of the climatic elements from the previous day is calculated for each macro-scale airflow pattern. But, it is limited when the pattern of the object day differs from the pattern of the previous day.

(2) From this data, a correlation coefficient matrix is calculated and eigen value, eigen vector and score for each principal component is calculated.

(3) Any component whose eigen value is larger than 1 may be accepted as a principal component because principal components must comprehensively express the characteristics of value.

In addition to this analysis, the 137 stations are randomly divided into two groups and principal component analysis is adopted to them. The upper components which are obtained from both of them is recognized as common principal components (Figure 10).

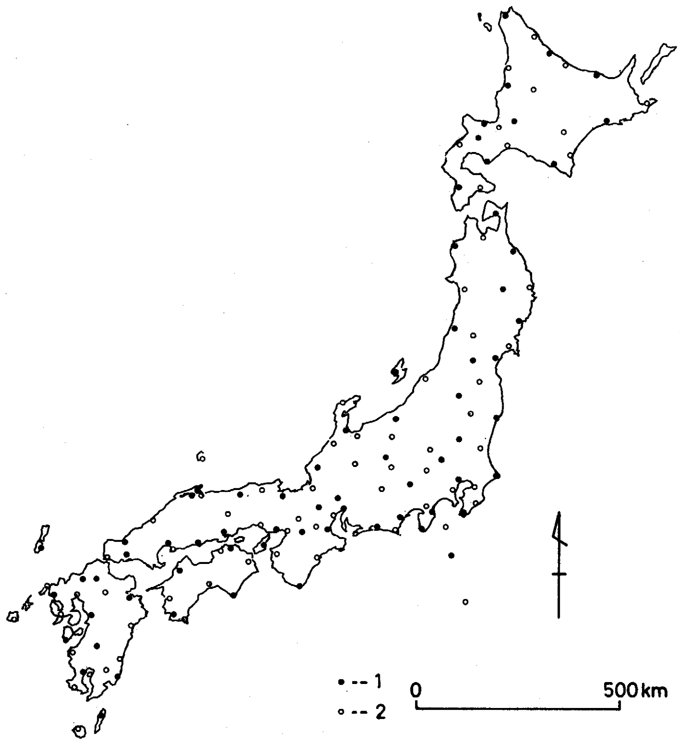


Figure 10 Locations of the meteorological stations used for principal component analysis
1. stations belong to particular group
2. stations belong to another group

Basic combination of climatic elements

Principal components are obtained for each macro-scale airflow pattern. The components of a-type are similar to each other. B-type components are also similar to each other as are c-type. Taking the cases of a_1, b_1 and c_1 types together, the eigen vectors show the framework of the synoptic climatological field and the relation between climatic elements (Table 2).

Table 2 Principal components for representative macro-scale airflow patterns

airflow pattern	a_1		b_1	c_1	
component number	1	2	1	1	2
eigen value	3.17	1.51	5.10	4.05	2.01
rate of trace (%)	40	19	64	51	25
eigen vector					
sea level pressure	0.25	−0.44	0.25	0.02	−0.65
air temperature	0.42	0.38	0.37	0.35	0.35
water vapour pressure	−0.32	0.51	−0.34	−0.31	0.48
relative humidity	−0.51	0.02	−0.42	−0.46	0.19
wind speed	0.06	0.42	0.20	0.27	0.09
cloud amount	−0.34	−0.21	−0.39	−0.38	−0.33
duration of sunshine	0.46	0.23	0.42	0.45	0.15
precipitation	−0.25	0.35	−0.37	−0.40	0.24

Less than three principal components are decided for each macro-scale airflow pattern. The principal components explain a variance more than 60% for a_1, b_1 and c_1 types in the contributive ratio of eigen value. The resulting principal components explain well the framwork of the synoptic climatological field.

Eigen vectors of the first component are similar in each macro-scale airflow pattern. The eigen vector is positive value for sea level pressure, temperature and sunshine duration, but negative for water vapour pressure, cloud amount and precipitation. Here the mean deviations from the previous day are used as the data. Consequently the first component shows variation in that temperature rises but precipitation decreases. Considering the other climatic elements together, the first component may be expressed as a variety of conditions from the fine, warm, dry conditions near anticyclones to the cloudy, cool, wet conditions near cyclones. This corresponds to the usual change of the synoptic climatological field. It is rain to fine or fine to rain according to movements of cyclones and anticyclones. Accordingly the first component should be a factor which shows this fine-cloudy condition.

Eigen vectors of the second component are similar in each macro-scale airflow pattern, too. The eigen vector shows larger positive values for temperature and water vapour pressure, but extreme negative value for sea level pressure. The principal components do not correlate with each other and the second component should express from warm and wet conditions near cyclones and local depressions to cool and dry conditions near anticyclones. These conditions cannot always be delineated as fine or cloudy since the second component is related to air mass, while the first component is related to pressure systems. The second component is a factor which explains advection flow.

Expression of fundamental climatic condition by principal component

The score of each component expresses the degree to which it influences the fine-cloudy factor and/or the warm-cool factor for each station. The distribution pattern of each score is simpler than the corresponding pattern for each climatic element (Figure 11).

For a_1 type the score of the first component is at its maximum in central Japan. In a_1 type traveling anticyclones often cover the Japanese Islands. High score areas show fine weather in the center of traveling anticyclones. The score of the second component is high inland and low on the coast. When traveling anticyclones pass through a local depression appears inland and there is a warming trend. High score areas show warm and humid conditions with inland local depression.

For b_1 type, the score of the first component is high in northern Japan and low on the Southern Coast. There are anticyclones in the Japan Sea and cyclones and fronts on Southern Coast. High score areas show fine weather on the anticyclone side and low score areas show rainy weather on the cyclone side.

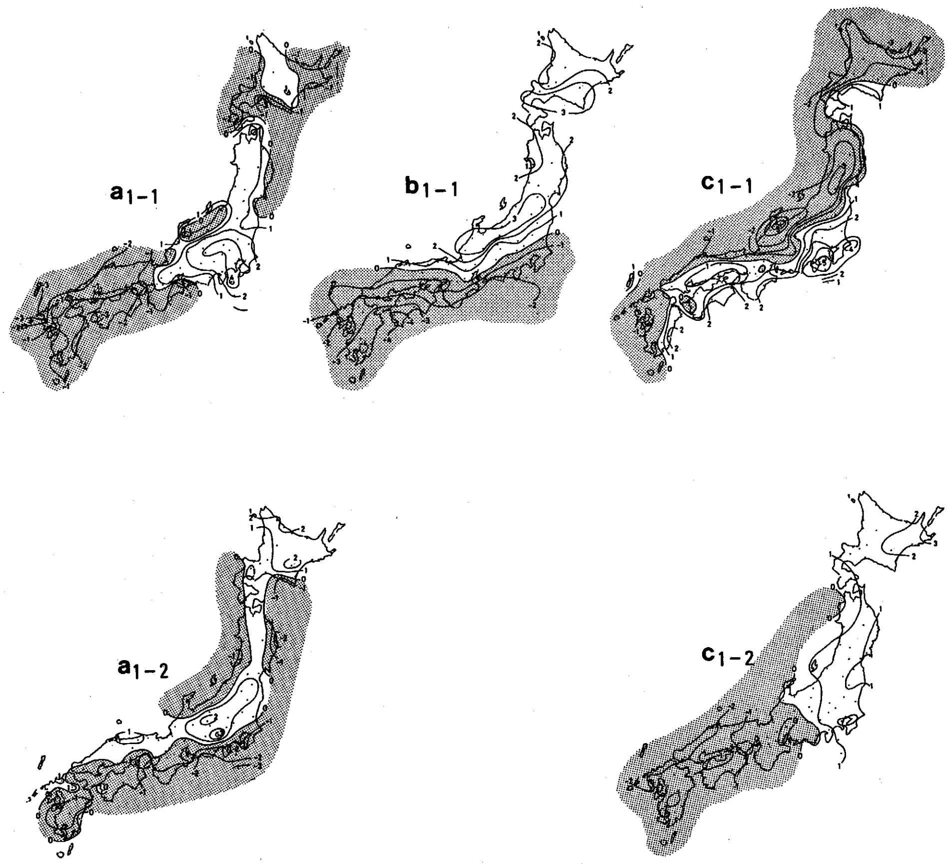


Figure 11 Distribution of score of the principal component
Hatched area expressed minus value of score
(cf. Table 2)

For c_1 type, the score of the first component is high on the Pacific Ocean side and low on the Japan Sea side. The absolute value is very large on both sides of the Chubu Mountain area and in the Kanto and Hokuriku Districts. Northwesterly monsoons blow. Distribution of the score shows that it is fine on the leeward side of the Chubu Mountain area or any dividing mountain range, while it is cloudy on the windward side. The score of the second component is high in eastern Japan and low in western Japan. For c_1 type there is a cyclone east of the Strait of Soya. High score areas show the warm area near this cyclone and low score areas show the cool area near the continental anticycone.

Major factors of Japanese climate

As was made clear by discriminant analysis in chapter 4, the distribution of climatic elements for each macro-scale airflow pattern expresses the actual pattern. This climatic pattern was discussed in chapter 5. In this chapter, principal component analysis will be made combining the climatic elements. This will allow climate to be discussed comprehensively from the point of all the climatic elements. For this principal component analysis, the controlling factors for the Japanese climate are as follows.

The first climatic factor is the strike of Japanese Islands and its turning. The eigen vector of sea level pressure is high on the first component of a_1 type, the first component of b_1 type and the second component of c_1 type (Table 2). Comparing the distribution of sea level pressure (Figure 7) and their score (Figure 11), the score is always high on the anticyclone side but low on the cyclone side. The difference between each pattern is caused by the position of the pressure system. As previously mentioned, cyclones in the Japan Sea are *a*-type, those on the Southern Coast are *b*-type and those on the Eastern Coast are *c*-type (Figure 5). These three areas in which cyclones lie are based on the turning of the strike of the Japanese Islands.

The second climatic factor is the dividing mountain range which has a distinct effect on the distribution of the first components score. The distribution of this score is not similar to the pressure system. Furthermore, the factor loading of sea level pressure is low in the eigen vector of this component. Topography is the only influence. For the first component of b_1 type, the score is lower toward the cyclones on the Southern Coast. The lower area corresponds to the southern side of the dividing mountain range in western Japan. For b_1 type, since the influence of the Japanese Islands strike and dividing mountain range appear in the same area, only one principal component is obtained and its eigen value is high (Table 2).

The third climatic factor is the distribution of land and sea. The differences between the coast and inland is shown in the distribution of the second components score for a_1 type (Figure 11). The influence of dividing mountain range does not appear for a_1 type. This may be because the wind is weakened by traveling anticyclones and orographic convection does not appear.

7. The Synoptic Climatological Process on Macro-Scale Aiflow Patterns

Climatic factors and their influence on the Japanese Islands

As mentioned in chapter 6, the fundamental conditions of climate are clearly defined by the features of climatic element distribution for each macro-scale airflow pattern. The climatic factors of the strike of the islands, the dividing mountain range and land-sea distribution are also determined. In this chapter, the specific synoptic climatological process for each macro-scale airflow pattern is analyzed based on those fundamental conditions and climatic factors.

Local circulation as affected by land-sea distribution

Sea breezes blow on the coast of Japanese Islands in a_1 and a_3 types (Figure 3). There is a distinctive difference between the inland and the coast for the distribution of air temperature (Figure 8), relative humidity, sea level pressure (Figure 7) and frequency of precipitation (Figure 9). Land-sea distribution effects those distributions (Figure 11).

Inland warm areas appear in Hokkaido, the southern part of the Tohoku District, the Kanto District, the Nobi Plain, the Kinki District, the Inland Sea of Japan and Kyushu. Isopleths of air temperature and relative humidity run parallel to the coast line showing the distinct effect of land-sea distribution. However, the isopleths run smoothly, unaffected by indentations in the coastline such as the Bay of Tokyo or the Inland Sea of Japan. Also, the gradients of temperature and relative humidity are steeper near the coast while they are loose inland.

On the other hand, depressions appear only inland in the Chubu District. Wind direction alters counterclockwise there and winds converge toward the center of the district. Inland depression corresponds to warm areas indicating local thermal cyclones. Another inland area of frequent rain is that limited from the southern part of the Tohoku District to the Chubu District. This is caused by thermal convection in the local thermal cyclone.

The difference between distribution of air temperature (Figure 8) and distribution of sea level pressure (Figure 7) is recognized as follows. A cooling zone is formed along the narrow coast followed by inland warming all over the islands. On the other hand, convection heating of large mountains is necessary to form local cyclones and convective rain. Consequently such conditions appear only around the Chubu Mountains which are the largest mountains in Japan. Furthermore local cyclones are not formed in Hokkaido in spite of its steep temperature gradient. The stable lower atmosphere in summer keeps convection from developing and as a result, local cyclones do not appear.

The Chubu Mountains also have an affect as a climatic factor for a_4 type which is characterized by strong southwesterly winds. Water vapour pressure is high on the Southern Coast and the Eastern Coast of the Tohoku District while it is warm and dry on the Japan Sea side. This warm area lies from the Hokuriku District to the southern part of the Tohoku District. The warm area is distinctive on the leeward side of the Chubu Mountains. Sometimes a föhn is caused by southerly winds which blow into the Japan Sea cyclone (Toyama Observatory, 1967). The warm area should be this föhn area. A föhn in the Chubu District is caused by the fact that the Sothern Coast is warm and humid. It is also caused by the presence of the Chubu Mountains.

Zonal separation related to the strike of Japanese Islands

For b_2 and b_3 types southerly winds blow in northeastern Japan, while northerly winds blow in southwestern Japan (Figure 3). Precipitation frequency is low in northeastern Japan, while it is high in southwestern Japan (Figure 9). Northeastern Japan is influenced by anticyclones, while southwestern Japan is influenced by cyclones. The subsequent regional difference in precipitation frequency and other factors is most distinctive for these types. Cyclones are on the Southern Coast for these types. As previously mentioned, this is related to the effect of the strike of the Japanese Islands (Figure 11).

The cloud amount is high on the Southern Coast and decreases gradually toward the Japan Sea side. Sunshine duration is less than one hour on the Pacific Ocean side, while it reaches five hours on Japan Sea side. The value of each climatic element increases or decreases along meridional direction, but none of the gradients are steep. These factors are affected only by the pressure system.

Temperature and other related elements are different on either side of the Suzuka Mountains in the Kinki District. For b_3 type, Yamase, easterly wind, blows on the Pacific Ocean side of northeastern Japan. There is precipitation along the coast and it is very cool. The light rainy area which is caused by Yamase reaches the rainy area on the Southern Coast. Temperature falls distinctively toward inland in the Chubu District and the Nobi Plain. Also, frequency of precipitation increases locally on the eastern foot of the Kii Mountains. Wind direction is biased east in this case. The Kii Mountains which run along meridional direction should have an effect on the precipitation frequency. However, the influence is less than that of the dividing mountain range. This slight influence is caused by its small scale and gentle wind.

Dividng mountain range deformation of airflow

For c type, distribution of climatic elements is different for the Japan Sea side and the Pacific Ocean side. On the Japan Sea side, as compared with the Pacific Ocean side, temperature is low, cloud amount is high, sunshine duration is short, water vapour pressure, relative humidity and frequency of precipitation are high and evaporation is low. Although the differences in these features are affected by the dividing mountain range, this is not the only factor which has an effect on the distribution of climatic elements for c type. For example, the discontinuous region of distribution is not always clear except around the Kanto Mountains and the Hida Mountain Range, which are the highest of the dividing mountains. Pressure systems, Chubu Mountains and other smaller mountains also have an effect. These climatic factors are further examined in the following paragraphs.

Climatic element distribution is somewhat continuous in northeastern Japan because this area is near the center of the cyclone. Hokkaido especially shows this effect. Winter-type precipitation is not limited to the windward side of the dividing mountain range in northeastern Japan; precipitation appears as snowfall around the center of the cyclone. In the same fashion distributions of other climatic elements are consistent over northeastern Japan.

The value of climatic elements is quite different between the windward and leeward sides of the Chubu Mountains. Also, the score of the first component for c_1 type is lowest in the Hokuriku District and highest in the Kanto District (Figure 11). On the leeward side, the Kanto District and the Tokai District, winds converge (Figure 3) and local cyclones are formed (Figure 7). The Boso Line of Discontinuity extends from these local cyclones (Nomoto, 1975). A warm area lies on leeward side, but its position does not coincide with the convergence area. The line of discontinuity causes air temperature to drop on the leeward side. The warmest area lies on the southwestern side of this convergence region. Warm air, which has turned around the Chubu Mountains, comes in from the southwest. Consequently, local cyclones on the leeward side of the Chubu Mountains are formed dynamically, not thermally.

Strong winds blow in the Strait of Tsugaru, the Strait of Kanmon and the Strait of Osumi (Figure 3). Each region is between mountains and they are called "wind gap" (Komabayashi and Nakamura, 1976). On the forward of mountains which are on the leeward side of the wind gap, precipitation also appears (Suzuki, 1961a). Example regions are the western foot of the Hidaka Mountain Range and the southwestern part of Shikoku. The Izumi Mountains and the Sanuki Mountains also show this characteristic.

8. Year Long Climatic Conditions in the Japanese Islands

Yearly variation of macro-scale airflow patterns

Considering climate as the accumulation of daily weather, climate and its variations in the Japanese Islands have been clarified by the occurrence of macro-scale airflow patterns. This has proven to be a good index of climatic conditions.

Climate, especially climatic change, is usually studied based on montly mean value. Therefore, climatic element variation is only compared with the long range variation of global circulation. According to macro-scale airflow patterns, however climatic change may be recognized by the phenomena of "synoptic weather chart" scale.

There are four seasons of macro-scale airflow patterns (Figure 4). Summer is from the middle of May to the middle of September and *a*-type prevails. Winter is from the beginning of November to the end of March and *c*-type prevails. Climatic change almost always depends on these summer and winter conditions and the frequency of yearly variations of macro-scale airflow patterns is analyzed using these conditions for the 10 years from 1968 to 1977 (Figure 12).

Yearly variation in the frequency of macro-scale airflow patterns for summer is quite distintive. Frequency of a-type has three maxima in these ten years. In 1973, there was little rain during the usual rainy season (kaminari-tsuyu or kara-tsuyu) and drought and water shortage occurred. It was also a severe summer. Tokyo had eighteen consecutive tropical days (manatsubi). The heat of late summer (zansho) continued until early in October (chushu). This "zansho" condition repeated itself in 1975.

A-type conditions were minimal during these 10 years and *b*-type was more the norm. In 1971, summer was quite short and cold-weather occurred in Hokkaido. Baiu began early, the second-baiu was violent and shurin was long. There was an over abundance of rain. In 1974, baiu continued for a long time and shurin was also long.

Frequency of macro-scale airflow patterns in winter shows distinctive yearly

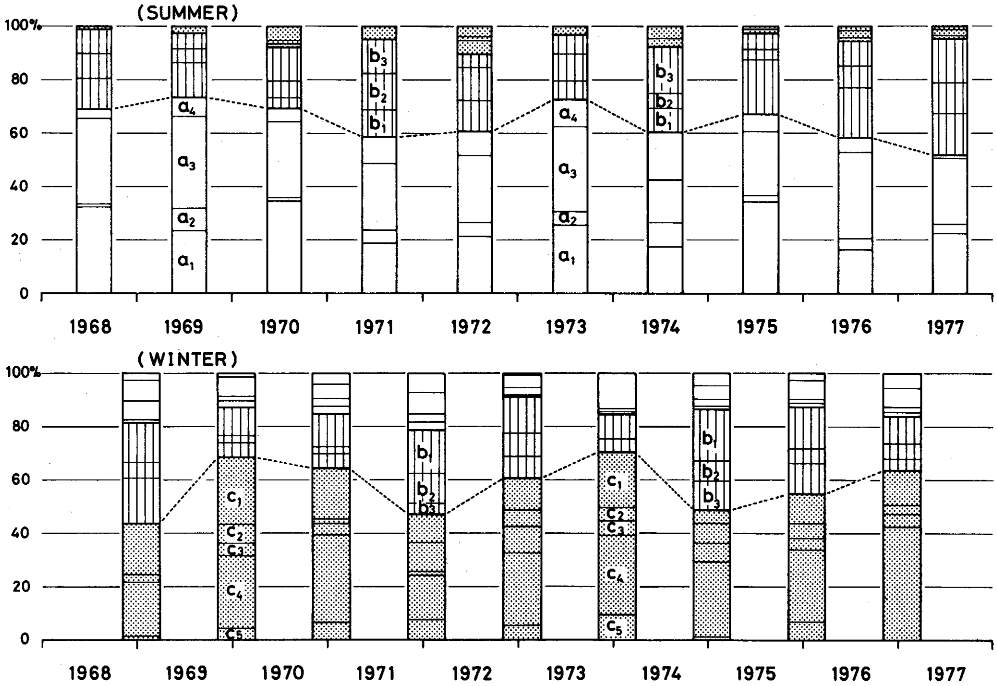


Figure 12 Yearly variation of appearance ratio of macro-scale airflow patterns
Summer is 27-52 pentad. Winter is 62-17 pentad (cf. Figure 4)

variation. Frequency of *c*-type had three maxima in nine winters. In 1969/1970, it was a cold winter and in December there was severe snowfall in the Hokuriku District. On the other hand, it was abnormally dry on the Pacific Ocean side. Tokyo did not get rain for 53 days from Decemer 8 to January 29. On March, there was a severe cold wave. 1973/1974 was also a cold winter, cold enough to freeze Lake Suwa (Omiwatari) for the first time in four years.

As with *c*-type was also minimal and *b*-type prevailed. The winter of 1968/1969 was mild with much rain on the Pacific Ocean side. During the winter of 1974/1975, pre-snowfall thunder (yukiokoshi) was a half month later than usual and there was no snowfall in the Hokuriku District until after the new year.

Yearly variaton of air temperature and precipitation

It is abnormally warm when there is a maximum *a*-type occurrence in summer and abnormally cold when there is a maximum occurrence of *c*-type in winter. Further, air temperature and precipitation in summer and winter are analyzed by relating them to macro-scale airflow patterns.

Summer 1973 shows maximum *a*-type and *b*-type prevails in summer 1976. Distribution of mean temperature and precipitation amount differs between the two summers (Figure 13). Temperatures are about 1°C higher in 1973 than in 1976. Differences are especially distinctive in the Tohoku District. The amount of precipitation is greater in 1976 than in

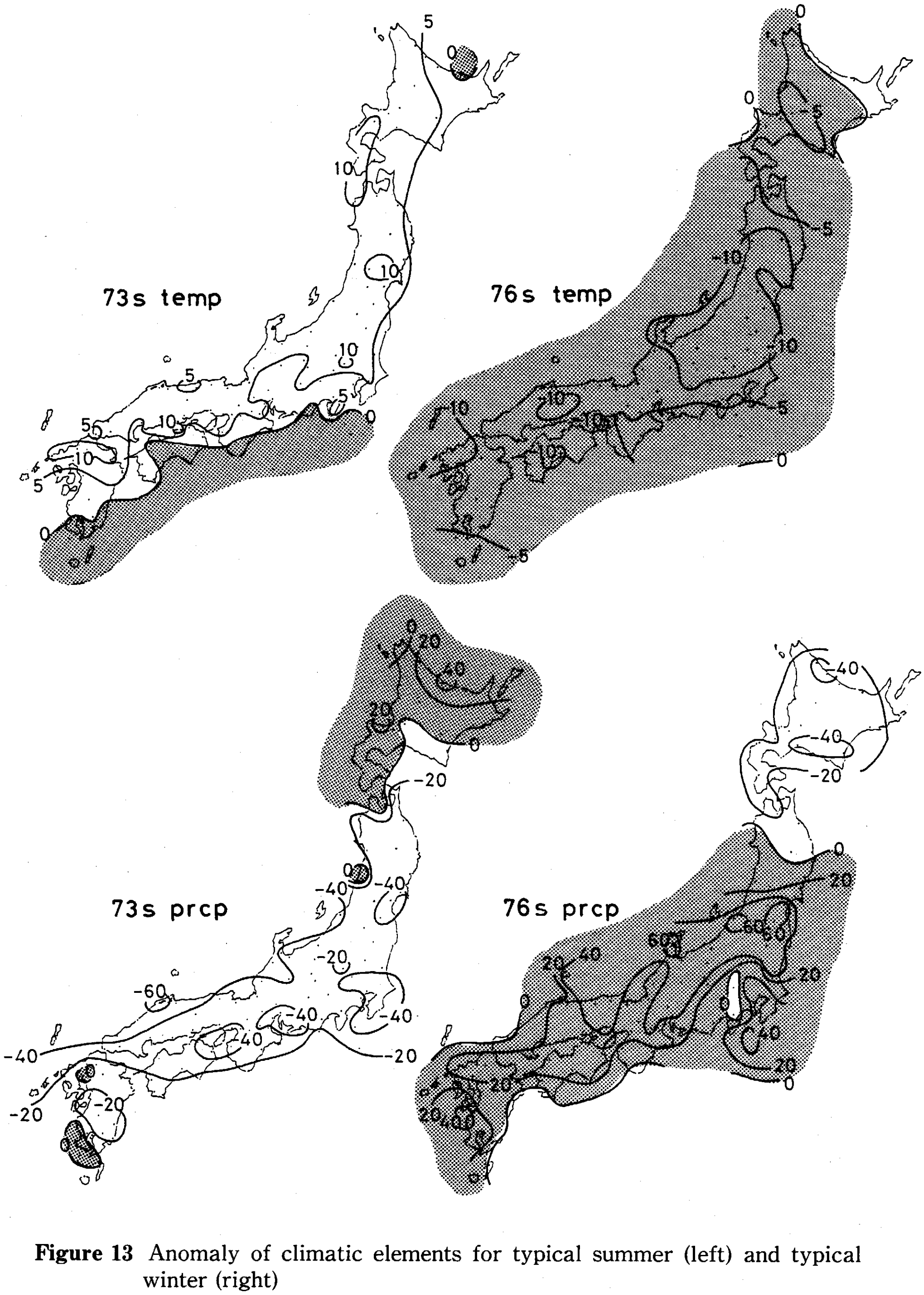
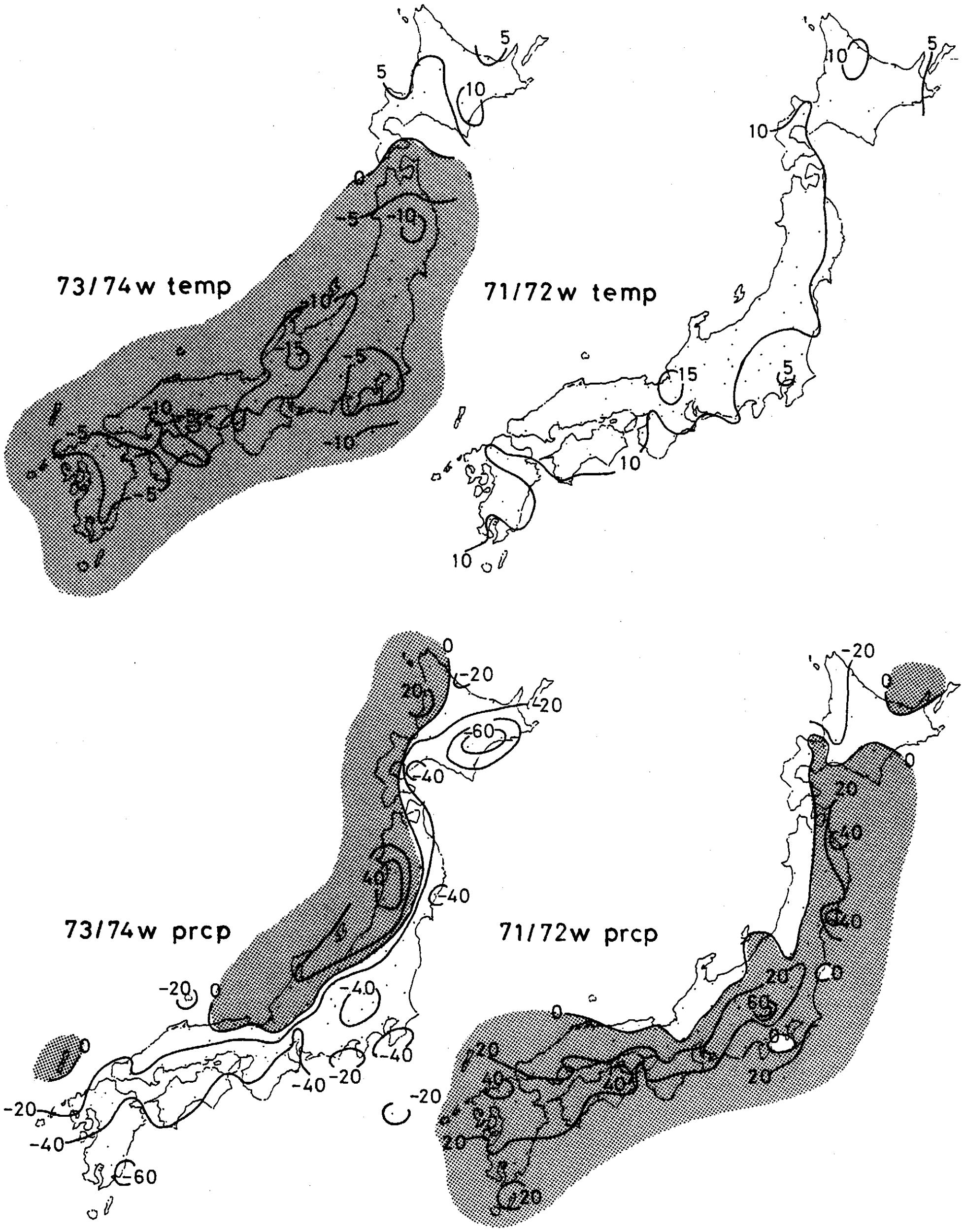


Figure 13 Anomaly of climatic elements for typical summer (left) and typical winter (right)
Temperature (0.1 ℃): Hatched area expressed cooler or colder than usual.
Precipitation (%): Hatched area expressed rainy or snowy than usual


73/74w temp
71/72w temp
73/74w prcp
71/72w prcp

1973. Especially on the Southern Coast, there is a lot of precipitation. Consequently, it can be concluded that it is warm and dry in an maximum a-type summer and cool and wet in a prevailing b-type summer.

Winter 1973/1974 maximum c-type and b-type prevails in winter 1971/1972. Distribution of mean temperature and precipitation amount differs between the two winters (Figure 14). In the Japan Sea side it was colder in 1973/1974 than in 1971/1972. However in the Pacific Ocean side was milder in 1973/1974 than in 1971/1972. The amount of precipitation was greater in 1973/1974 than 1971/1972 on the Japan Sea side. However on the Southern Coast it was less in 1973/1974 than in 1971/1972. Thus, it can be concluded that it is cold with much rain (snow) on the Japan Sea side during a maximum c-type winter and that it is cold with much rain on the Pacific Ocean side during a prevailing b-type winter.

Variation of summer conditions and winter conditions

Climatic change in the Japanese Islands has typical characteristics. Summer conditions and winter conditions correspond over the ten year period examined. That is, when it is mild and there is little snow in winter, it is cool and there is a lot of rain in summer. On the other hand, when it is cold and there is much snow in winter, it is warm and there is little rain in summer (Yamamoto, 1967). The trough of ultra-long waves near the Japanese Islands is biased toward east or west continuously. This causes climatic changes. When the trough is biased toward the west, the "cold winter/warm summer" conditions appear. When the trough is biased toward the east, "warm winter/cool summer" conditions appear (Yamamoto, 1971).

The object of this study has been the conditions of each year and not those of the ten year mean. Maximum a-type summer is followed by maximum c-type winter in about a four year cycle of variation. That is to say warm summers should relate to cold winters.

9. Conclusion

Climate is the whole atmospheric phenomena and is consequently expressed as the accumulation of daily weather. However, daily weather alters and it is different in each region of the globe. Thus, it is difficult to grasp climate as weather accumulation. In this study, macro-scale airflow patterns were set up, and used to determine climate in the Japanese Islands.

The weather was analyzed according to synoptic climatology with the object being airflow patterns in the Japanese Islands. Surface wind distribution at 15:00 JST was classified using cluster analysis and macro-scale airflow patterns were set up according to the results. Twelve types of macro-scale airflow patterns: a_1-a_4 type (southerly wind), b_1-b_3 type (northeasterly wind), c_1-c_5 type (northwesterly wind) were obtained (Chapter 2). Next, seasonal frequency changes for macro-scale airflow patterns were clarified. Surface and upper synoptic climatological fields for each macro-scale airflow pattern were also clarified. Characteristic season and cyclone areas related to macro-scale airflow patterns were determined. The seasons were summer (a-type prevail), winter (c-

type prevail), spring and autumn (*b*-type prevail). The cyclone areas were the Japan Sea, the Eastern Coast and the Southern Coast (Chapter 3). Discriminant analysis was employed to examine macro-scale airflow patterns for their useability as an index of the synoptic climatological field. Such analysis indicated that distribution of climatic elements as classified by macro-scale airflow patterns differed from each other. This ascertained the adoptability of macro-scale airflow patterns as an index for clarifying the distributions of the ten climatic elements (Chapter 4). The features of this analysis are as follows (Chapter 5).

(1) the effect of large mountains

(2) the difference between northeastern Japan and southwestern Japan

(3) the difference between the Japan Sea side and the Pacific Ocean side of the dividing mountains

(4) the difference between inland and coast

Based on the results of this investigation, fundamental conditions of climate and its variation are analyzed for the Japanese Islands. First, principal component analysis was used with the objective of determining the weather for each macro-scale airflow pattern. This revealed fine-cloudy and warm-cool weather factors. The fact that fundamental weather conditions are controlled by the strike of Japanese Islands, the dividing mountain range and land-sea distribution also became clear (Chapter 6). Based on this, the synoptic climatological process of weather for each macro-scale airflow pattern was discussed. In this process, other factors affecting climate in the Japanese Islands included the Chubu Mountains for *a*-type, the Kii Mountains for *b*-type and small mountains for *c*-type (Chapter 7). Next, climatic variation was analyzed according to the frequency of macro-scale airflow patterns. The frequency in summer and winter relates to mean temperature and precipitation amount; *a*-type maximum summer is warm and *c*-type maximum winter is cold. Further, warm summers seem to be followed by cold winter (Chapter 8).

As described above, macro-scale airflow patterns were used as one method of studying the climate of Japan. The significance of macro-scale airflow patterns is as follows. Climate is clarified by analysis of climatic elements, regional distribution and time series (Godske, 1966). Macro-scale airflow patterns are available to analyze the climate, because the weather condition pattern is latent and macro-scale airflow patterns express this latent pattern. Consequently, climate is clarified as weather accumulation by macro-scale airflow patterns. The final purpose of this study was the establishment of fundamental conditions of climate. Some of the results may be used for another study about atmospheric phenomena which will also provide basic information for the study of variations between atmospheric, oceanic and other systems.

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