CYCLONE FREQUENCY IN EAST ASIA AND DOUBLE-CYCLONES

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Abstract Japanese meteorologists call a certain type of cyclone "Futatsudama-teikiatsu" (Double-cyclone). The relationships between frequencies of extratropical cyclones and Double-cyclones were studied. Using a 2° latitude/longitude grid covering East Asia, three high frequency belts were found. Double-cyclones were classified into three types. Features of occurrence of these three types were discussed.

1. Introduction

East Asia is one of the most active region of extratropical cyclones. Therefore, cyclones exert considerable influence on Japanese weather. However, climatological studies on cyclones is not very popular in Japan.

Yoshino (1955) studied the precipitation in Kantō during extratropical cyclone movement along the Pacific coast of Japan. Chung et al. (1976) compared lee cyclones in East Asia with those of Canada and pointed out that there are three principal tracks in East Asia which correspond to the three mean jets of the upper troposphere. Tasaka (1980) studied the relationship between the distribution of precipitation in Japan and cyclone location. Bibliographies and summaries of works on cyclones have been given by Klein (1957), Chung et al. (1976) and Hayden (1981a).

In East Asia, a single trough is often expressed as two or more cyclones on surface synoptic charts. In this case, two cyclones situated simultaneously to the north and south of Japan are called "Double-cyclones" by Japanese meteorologists (Fig. 1). Double-cyclones sometimes bring severe weather in broad parts of Japan.

The aim of this study is to clarify climatologically the relationship between Double-cyclones and cyclonic activity over East Asia using the frequencies of cyclones, cyclogenesis and principal tracks.

2. Data and Cyclone Occurrence Mapping

Data

Locations of cyclone centers and cyclogenesis (first appearance on a surface synoptic chart) were counted on a 2° latitude/longitude grid using the twice-daily surface synoptic charts published by the Japan Meteorological Agency. The period is from January 1975 to

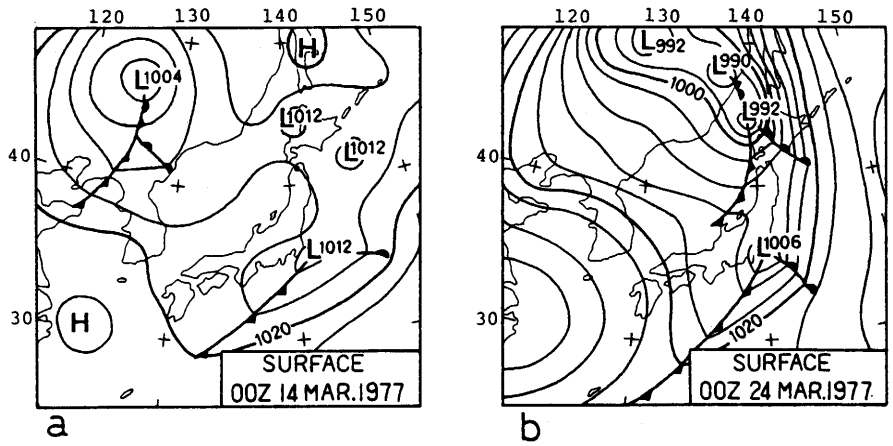


Fig. 1 Synoptic surface patterns of cyclones in East Asia
a. Ordinary pattern b. "Double-cyclone" pattern

December 1979. Extratropical cyclones used in this study satisfy the following criteria:

(1) Cyclones which could be followed on two or more successive surface synoptic charts.

(2) Frontal system was analyzed from the center of a cyclone during its movement in the study area (Fig. 2).

(3) Central pressure of cyclones which had no frontal system must be 1000mb or less.

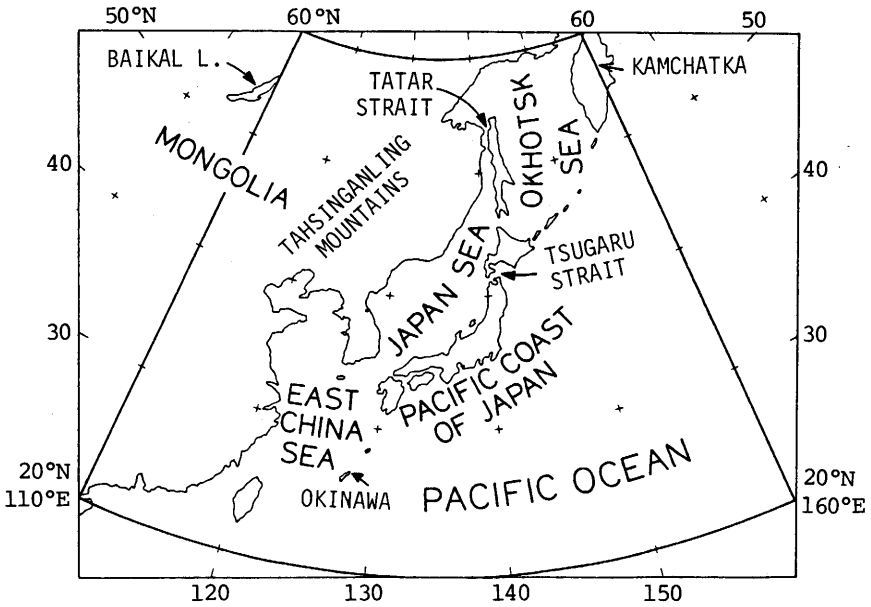


Fig. 2 Study area and locations cited

Method of mapping

There are two problems concerning cyclone frequency mapping:

(1) What kind of grid should be used?

(2) How should cyclones be counted on the grid?

For the first problem, Ballenzweig (1959) showed that we should use equal-area grid, because area-normalization distorts the distribution pattern. For example, Klein (1957) adopted equal-area grid. Recently however, Hayden (1981b) has stated that the distortion derived from area-normalization did not change the results of his study. Most works have used area-normalization (Damman 1960, Taljaard 1967, Reitan 1974, 1979 and Zishka and Smith 1980).

In this study, the author adopted area-normalization. The area of one unit cell is 40,500km^2, corresponding to a cell between 34° and 36°N. The total frequency of cyclone occurrence and cyclogenesis was calculated for each season for five years. Then, to smooth the distribution pattern, a three-point running mean was applied for each zone of 2° latitude.

For the second problem, there are two methods of counting:

(1) The first method is based on cyclone tracks. A cyclone occurrence event is counted when a track crosses a grid cell.

(2) The second method is based on synoptic charts. A cyclone occurrence event is counted when a cyclone center is situated in a grid cell.

The author adopted the second method and counted cyclone occurrence events according to the location of the twice-daily cyclone center. When a slow-moving cyclone appeared in a grid cell on more than two sheets, it was counted repeatedly. Cyclone occurrence frequency maps in this study therefore show the duration of cyclonic activity. These maps can express stationary cyclones climatologically.

3. Features of Cyclone Frequency

Figure 3 shows the cyclone frequency of each season.

Winter (Dec., Jan., Feb.)

The highest frequency of more than 25 is in the northern part of the Okhotsk Sea. Areas of 15 are in the south of Kamchatka and the east of Japan. In the Japan Sea along 40°N, there is an area of more than 10. As a whole, two high frequency belts can be observed. On the continent, the frequency is very low because of the dominant Siberian high.

Spring (Mar., Apr., May)

The most evident high frequency belt extends from the East China Sea through the south of Japan to the south of Kamchatka. This belt is clearest during this season. The belt in the Japan Sea covers the Tatar Strait, whereas during the other three seasons it covers the Tsugaru Strait. The high frequency belt on the continent is centered near 50°N, and the high frequency area of the Okhotsk Sea shrinks.

As a whole, there are three high frequency belts. The eastern parts of the Japan Sea belt

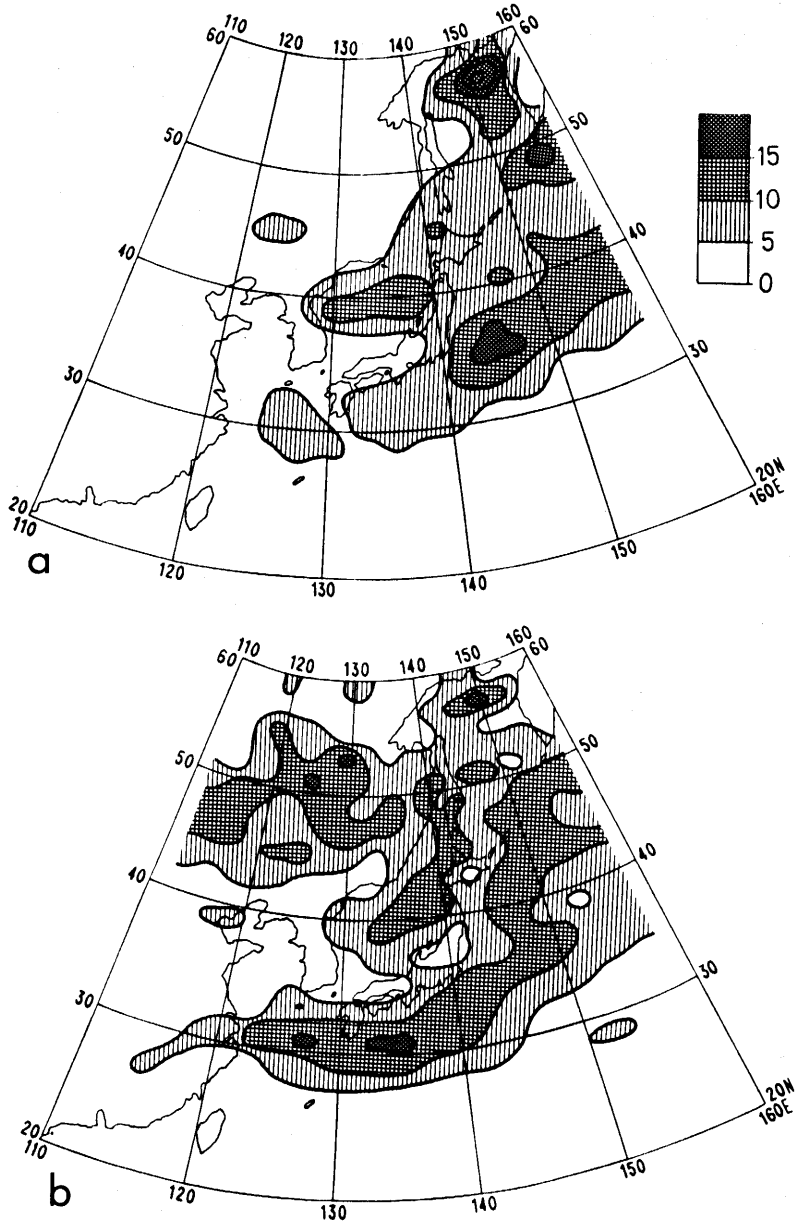


Fig. 3 Area-normalized pattern of cyclone occurrence frequency for five years
The area of a unit cell is 40,500 km^2.
a: Winter, b: Spring, c: Summer, d: Autumn. See Fig. 2 for locations

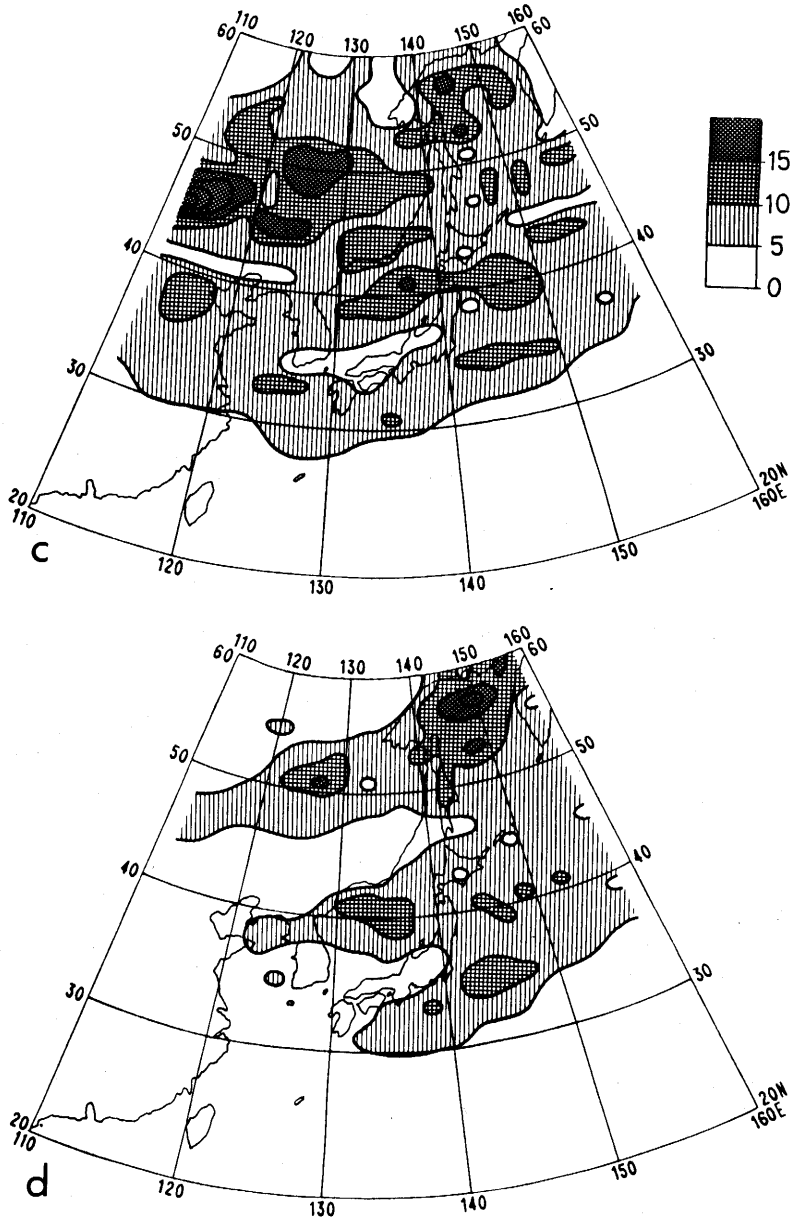


Fig. 3 (continued)

and the Pacific coast belt curve northward.

Summer (Jun., Jul., Aug.)

The highest frequency of 30 appears in Mongolia, with a wide belt of high frequencies lying along 45°N. Along 40°N from the Japan Sea to the east of Japan, an evident high frequency belt exists. The Pacific coast of Japan has no apparent belt. The position of the high frequency area of the Okhotsk Sea shifts westward.

As a whole, the distribution of frequency shows a scattered pattern. However, three belts can be recognized. The reason for the unclearness of the Japanese Pacific coast belt is the dominant North Pacific anticyclone.

Autumn (Sept., Oct., Nov.)

The highest frequency area is in the Okhotsk Sea. The Japan Sea high frequency belt streches along 40°N. Along the Pacific coast of Japan, a high frequency area exists at about 145°E.

As a whole, although their frequencies are low, three belt patterns are evident.

Annual summary

Three high frequency belts are recognized: (1) on the continent, (2) in the Japan Sea and (3) along the Pacific coast of Japan. These three belts correspond to the three principal cyclone tracks (Chung et al., 1976).

4. Mean Tracks

The lines drawn from western frequency maxima to eastern maxima suggest mean tracks because extratropical cyclones at mid-latitude move eastward. Figure 4 shows mean tracks of extratropical cyclones in East Asia based on Figure 3. The author named these three mean tracks as the Continent course, the Japan Sea course and the Pacific coast curse.

5. Definition and Classification of "Double-cyclones"

Cyclones of the Japan Sea course and of the Pacific coast course are termed Japan Sea cyclones and Pacific coast cyclones, respectively. Both are principal cyclones which directly affect Japanese weather. Cyclones of the Continent course scarcely affect the weather of the central part of Japan, so that they have no common name. In this study, they are termed Continent cyclones.

Japanese meteorologists usually consider the following two cases as "Double-cyclones":

(1) A Japan Sea cyclone and a Pacific coast cyclone coexist over Japan (see Fig. 5a).

(2) There is an occluded cyclone in the Japan Sea. From the center of it the occluded front crosses Japan, and on the occluded point in the Pacific Ocean, another cyclone center appears (see Fig. 5e).

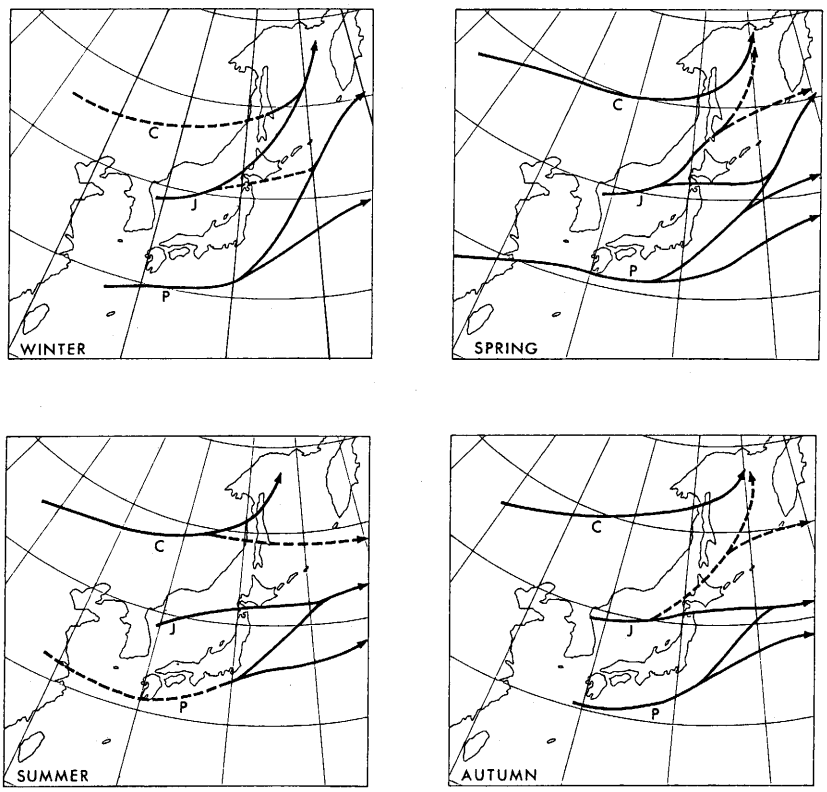


Fig. 4 Mean tracks of extratropical cyclones in East Asia
Broken lines show the obscure parts of each course.
C: Continent course, J: Japan Sea course, P: Pacific coast course

Definition

A "Double-cyclone" is defined climatologically in East Asia. "Double-cyclones" are cyclones which produce a "Double-cyclone pressure pattern". This pressuer pattern is defined as follows: "Two (or more) cyclones corresponding to a single upper trough exist over Japan, one is situated in the Pacific Ocean (along the coast of Japan) and the other is situated in the Japan Sea or on the Asiatic continent".

Classification

In practice, there are many variations of the Double-cyclone pressure pattern. In this study, three types of Double-cyclones are defined according to the three mean tracks in East Asia (Table 1).

Figure 5 shows the three types of Double-cyclones and some variations. The left three figures (a, c and e) show typical patterns. The right three figures (b, d and f) show variations. In these cases, there are three cyclones. For Figure 5b, the cyclones B and C compose a Double-cyclones of the Type 1. For Figure 5d, the cyclones D and F compose the Type 2, where cyclone E is a secondary cyclone of D. In Figure 5f, the cyclones H and I compose the Type 3. The cyclone G has no direct relation with H.

Table 1 Three types of Double-cyclones

	CYCLONE	
	North of Japan	South of Japan
Type 1	Japan Sea cyclone	Pacific coast cyclone
Type 2	Continent cyclone	Pacific coast cyclone
Type 3	Japan Sea cyclone	Cyclone on an occluded point of the Japan Sea cyclone

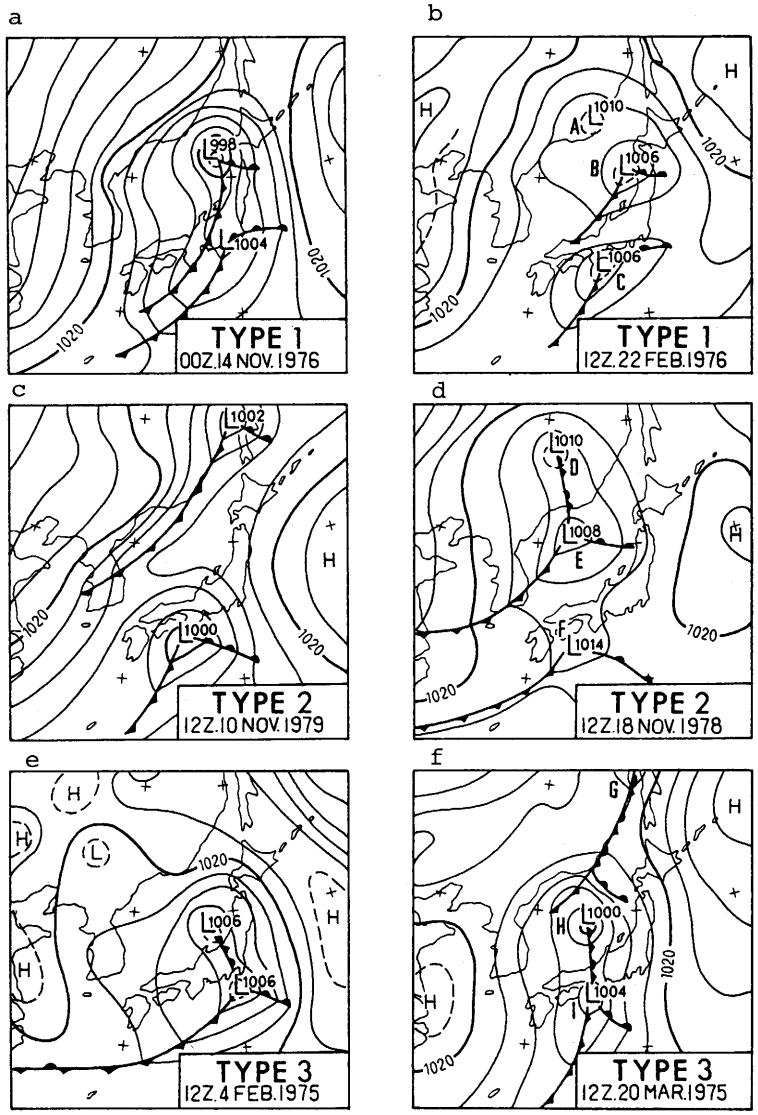


Fig. 5 The three types of Double-cyclone
a, c and e show typical patterns; b, d and f show variations

Selection of Double-cyclone cases

Cases of the Double-cyclones for five years (1975–1979) were selected according to six criteria:

(1) The cyclone could be followed on three or more successive surface synoptic charts.
(2) Frontal system was analized from the center of a cyclone during its movement in the study area.
(3) Central pressure of cyclones which had no frontal system must be 1000mb or less.
(4) Tropical cyclones (including typhoons) and extratropical cyclones originating from tropical cyclones were excluded.
(5) Frontal-wave cyclones on stationary fronts (e.g. Baiu-front) were excluded unless they developed into occluded cyclones in the Japan Sea and made the Type 3.
(6) Pacific coast cyclones which were situated far south of Japan were excluded.

Table 2 shows the numbers of the Double-cyclone cases used in this study.

6. Cyclogenesis of Double-cyclones

It is necessary for understanding the relationship between Double-cyclones and cyclonic activities in East Asia, to investigate the distribution of cyclogenesis.

Table 2 Occurrence of Double-cyclones

	MONTH												
Type 1	1	2	3	4	5	6	7	8	9	10	11	12	total
1975	0	0	0	1	0	0	0	0	0	1	0	0	2
1976	1	2	1	1	2	0	0	0	0	1	1	1	10
1977	0	0	0	0	1	0	0	0	0	0	0	1	2
1978	3	0	0	2	2	0	0	0	0	0	2	0	9
1979	1	1	2	1	2	1	0	0	0	0	2	0	10
total	5	3	3	5	7	1	0	0	0	2	5	2	33
Type 2													
1975	1	1	0	0	1	0	0	0	0	0	1	0	4
1976	0	0	1	0	0	0	0	0	0	0	1	0	2
1977	0	0	1	2	0	0	0	0	0	1	1	0	5
1978	0	0	2	1	0	0	0	0	0	0	1	0	4
1979	1	1	2	0	1	0	0	0	0	1	1	0	7
total	2	2	6	3	2	0	0	0	0	2	5	0	22
Type 3													
1975	0	1	2	1	0	1	0	0	0	0	1	0	6
1976	0	0	0	0	0	0	0	0	1	0	0	0	1
1977	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	1	0	0	0	0	0	0	0	0	0	0	0	1
1979	0	1	0	0	0	0	0	0	0	0	0	0	1
total	1	2	2	1	0	1	0	0	1	0	1	0	9

Features of cyclogenesis frequencies

Figure 6 shows cyclogenesis (the location of first appearance on surface synoptic charts) frequencies. This figure was made by the same method and criteria for the adoption of cyclones used for Figure 3.

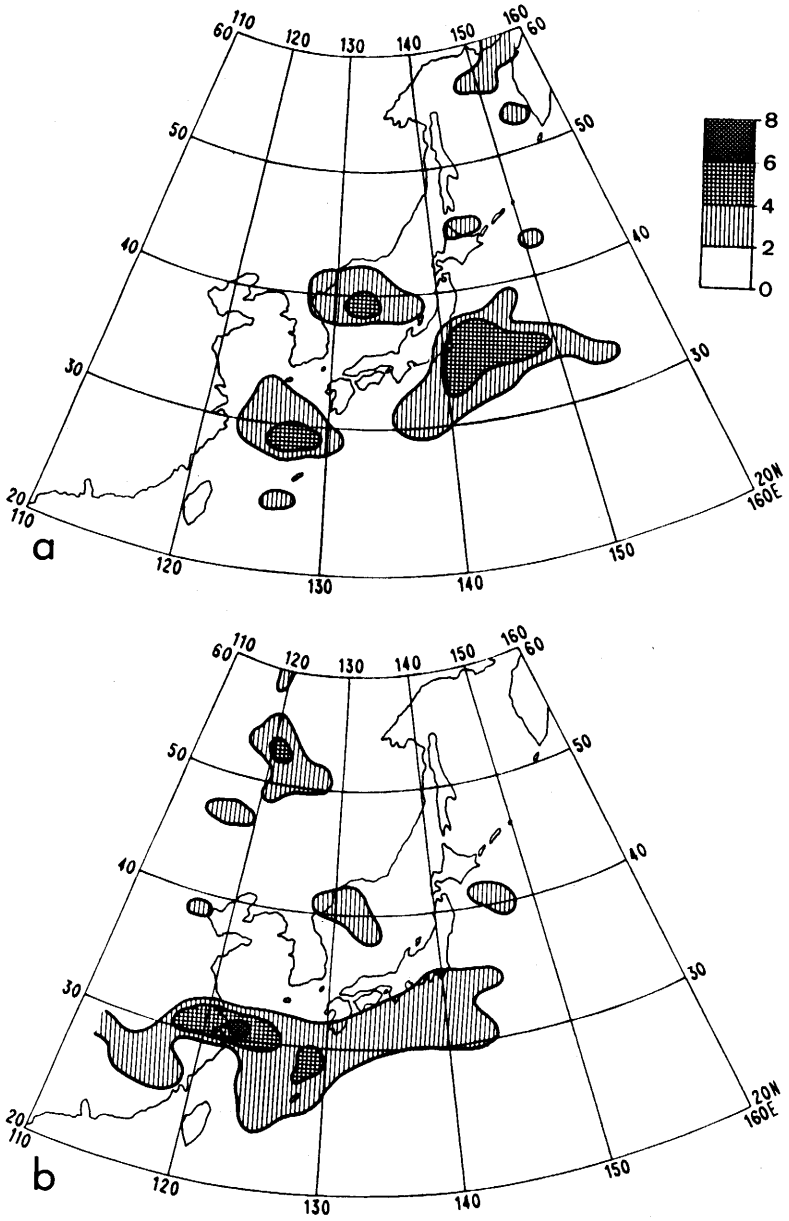


Fig. 6 Frequency of cyclogenesis. a: Winter, b: Spring, c: Summer, d: Autumn
Drawn for the same method of Fig. 3

(1) *Winter (Dec., Japan., Feb.)*

The main areas of genesis are in the Japan Sea, the East China Sea and the Pacific Ocean. Those of the Pacific Ocean is most evident in this season. On the continent, there is no evident area.

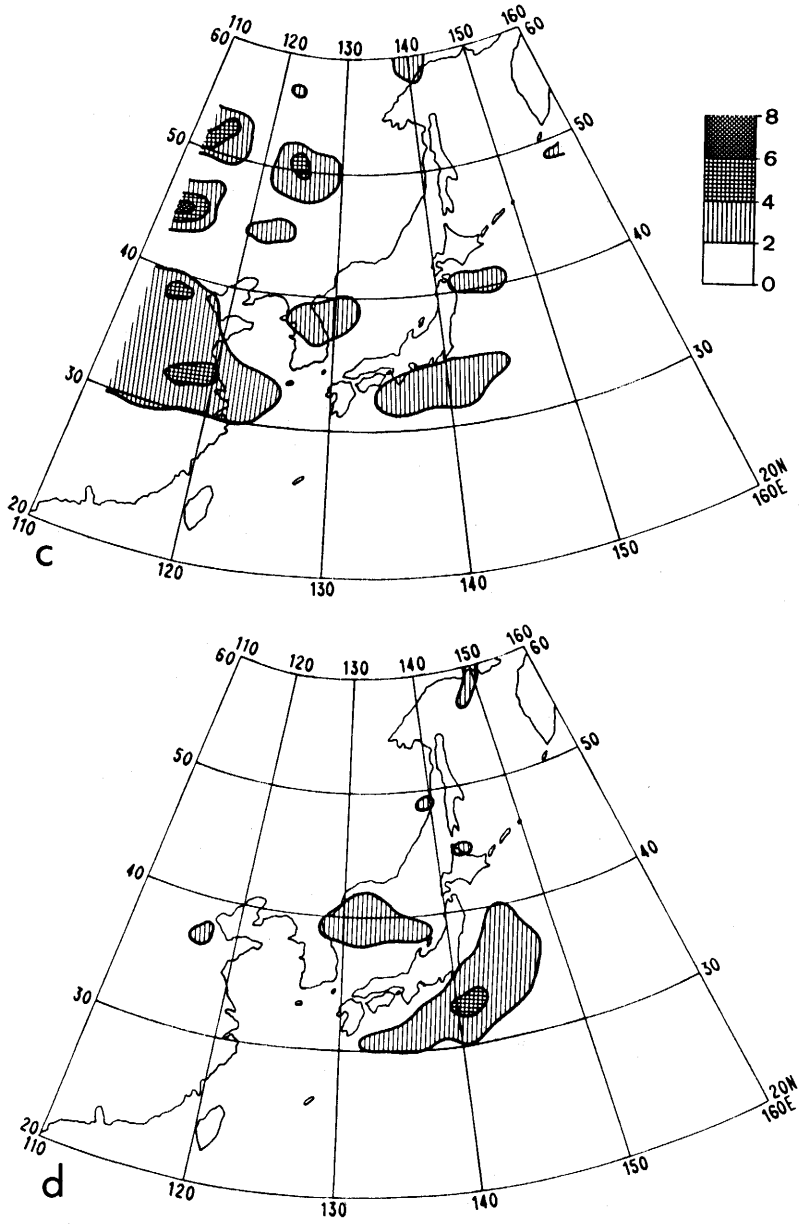


Fig. 6 (continued)

(2) *Spring (Mar., Apr., May)*

From the southern part of China to the Pacific coast of Japan along 30°N, there is a high frequency belt. Frequencies above 6 are found in the East China Sea. Another main area of genesis is a lee-side of the Tahsinganling Mountains.

(3) *Summer (Jun., Jul., Aug.)*

There is no evident area of genesis in the East China Sea. Frequencies along the Pacific coast of Japan are lowest in this season. On the continent, there are two high frequency areas, the lee-side of the Tahsinganling Mountains and Mongolia. In China, one broad area of genesis exists, but frequencies are not high.

(4) *Autumn (Sept., Oct., Nov.)*

Evident areas of genesis appear only on the Pacific coast of Japan and the Japan Sea. In the East China Sea and the lee-side of the Tahsinganling Mountains, there is no high frequency area.

(5) *Annual summary*

As a whole, there are five main areas of cyclogenesis, the East China Sea, the Pacific coast of Japan, the Japan Sea, the lee-side of the Tahsinganling Mountains and Mongolia.

(i) The east China Sea
High frequency areas appear in winter, centered near Okinawa Island, and in spring, centered near Shanghai.

(ii) The Pacific coast of Japan
This area exists in all seasons, but high frequencies appear in autumn and winter.

(iii) The Japan Sea
This area appears in all seasons, but it is most evident in winter.

(iv) The lee-side of the Tahsinganling Mountains
This area appears in spring and summer.

(v) Mongolia
This area appears only in summer.

Cyclogenesis of Double-cyclones

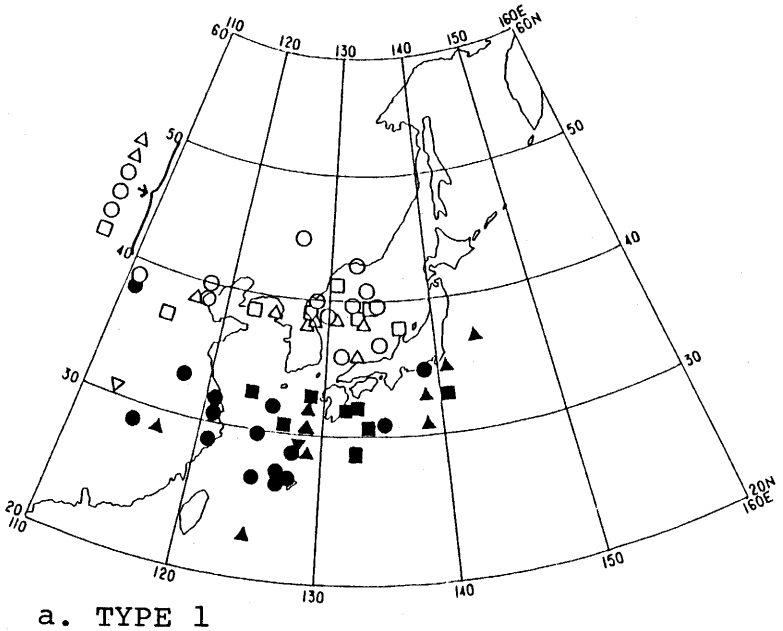
Figure 7 shows the locations of genesis of cyclones which compose Double-cyclones. Cyclones that move from the outside of the study area are shown in the left margin of the figures.

Type 1 (Fig. 7a)

Most Japan Sea cyclones are generated in the Japan Sea. Pacific coast cyclones are generated in the East China Sea and the Pacific Ocean.

In winter (triangles) and autumn (squares), Pacific coast cyclones are generated mostly in the Pacific Ocean near Japan. But in spring (circles), they are generated mostly in the East China Sea. This corresponds with the high occurrence frequencies in winter and autumn in the Pacific Ocean, with that of spring appearing in the East China Sea.

The cyclogenesis area of the Pacific coast cyclones is situated more to the east than that of the Japan Sea cyclones. The Pacific coast cyclones could be stronger than the Japan Sea cyclones because the Pacific coast cyclones move over the ocean for a longer time than the Japan Sea cyclones.



a. TYPE 1

LEGEND

	WINTER	SPRING	SUMMER	AUTUMN
Cyclones of North of Japan	△	○	▽	□
Cyclones of South of Japan	▲	●	▼	■
Cyclones that move from the outside of the study area, showing the latitudinal zone of entrance.	○ △ □ →			

Fig. 7 Locations of genesis of cyclones which make the Double-cyclones

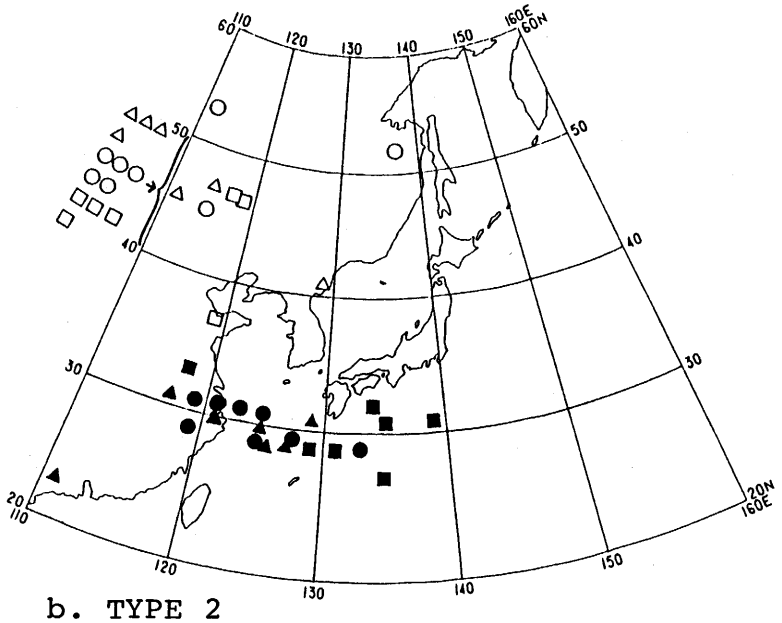
The Japan Sea cyclones which are marked in the margin of the figures were originally Continent cyclones. These take southern courses and cross the Japan Sea.

Type 2 (Fig. 7b)

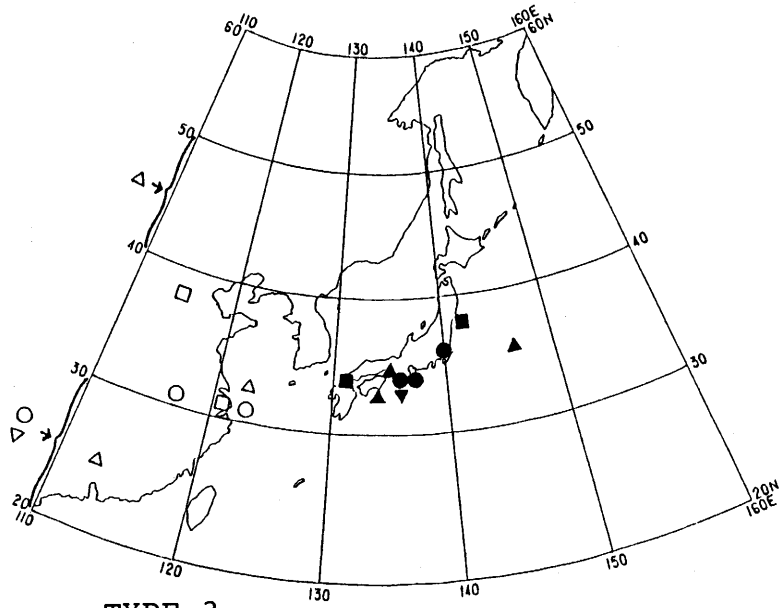
Most Continent cyclones are formed outside of the study area. Pacific coast cyclones are formed on the ocean along 30°N. As a whole, Continent cyclones are formed before Pacific coast cyclones. This suggests that the upper level trough of the Continent cyclone is relatively deep.

Type 3 (Fig. 7c)

The cyclones which compose the Type 3 are occluded Japan Sea cyclones. But the location of initial genesis is usually far west of Japan Sea and in some case in the southern part of China.



b. TYPE 2



c. TYPE 3

Fig. 7 (continued)

Wada (1973) suggested that cyclones which developed with less than 990mb in the Japan Sea were not formed in the Japan Sea, but rather came from the west. We may say that most Japan Sea cyclones of Type 3 are originated in the subtropical region.

7. Occurrence of Double-cyclones

Number of cyclones

The number of cyclones near Japan should be counted in order to know the features of occurrence of Double-cyclones. Therefore in the area near Japan enclosed by the lines of 20°N, 60°N, 120°E and 150°E, the number of cyclones were counted (Table 3).

The cyclones included in the count satisfy the following three criteria:

(1) Extratropical cyclones which could be followed on three or more successive surface synoptic charts (twice a day).

(2) Frontal system was analyzed from the center of a cyclone during its movement in the area.

(3) Central pressure of cyclones which had no frontal system must be 1000mb or less.

For the five year period, the total number of cyclones was 1341, and the yearly mean was 268.

Seasonal features of Double-cyclone occurrence

Table 4 was formed from Tables 2 and 3, and shows the numbers of Double-cyclones and extratropical cyclones for each season. Double-cyclones frequently appear in spring while in

Table 3 Numbers of extratropical cyclones which appeared in the area enclosed by 20°N, 60°N, 120°E and 150°E

CYCLONE WITH FRONT	MONTH												
	1	2	3	4	5	6	7	8	9	10	11	12	total
1975	14	18	25	20	25	19	17	8	22	25	13	21	227
1976	14	16	23	21	30	17	14	18	14	20	16	16	219
1977	15	15	17	17	21	18	14	15	10	20	16	12	190
1978	18	15	18	20	23	16	13	16	18	17	13	22	209
1979	18	22	23	25	19	23	18	10	15	19	20	12	222
total	79	86	106	101	118	93	76	67	79	101	78	83	1067
CYCLONE WITHOUT FRONT													
1975	2	2	2	9	6	13	8	6	1	2	0	2	53
1976	2	0	1	3	4	10	5	4	1	3	0	4	37
1977	4	7	8	5	9	7	8	4	4	0	4	6	66
1978	6	4	2	8	5	12	11	7	4	3	3	0	65
1979	2	3	5	5	6	10	2	10	3	2	3	2	53
total	16	16	18	30	30	52	34	31	13	10	10	14	274

Table 4 Numbers of Double-cyclones cases and cyclones with frontal systems. Each number shows the total of five years

	WINTER	SPRING	SUMMER	AUTUMN
Double-cyclones				
Type 1	10	15	1	7
Type 2	4	11	0	7
Type 3	3	3	1	2
(Total)	17	29	2	16
Cyclones with front	248	325	236	258

summer only two cases were found. For the numbers of cyclones, there are no noticeable differences among the three seasons, winter, summer and autumn.

The number of Double-cyclone cases is lowest in summer, and relatively low in winter and autumn. The reasons for this are as follows:

(1) *Summer*

The frequencies of occurrence and genesis of Pacific coast cyclones are very low, precluding Double-cyclones of Types 1 and 2. This situation is produced by the northward extension of the North Pacific anticyclone.

(2) *Winter*

The frequency of Continent cyclones is very low because of the existence of strong Siberian high. Therefore, Type 2 is mostly precluded (for example, winter 4, spring 11 and autumn 7).

(3) *Autumn*

In the East China Sea, the frequency of cyclogenesis is very low. Therefore, Types 1 and 2 are mostly precluded.

8. Summary

The present synoptic climatology on Double-cyclones in East Asia gave the following results:

1) In East Asia, there are three high frequency belts of cyclone occurrence. These correspond to the three principal tracks, the Continent course, the Japan Sea course and the Pacific coast course.

2) The Continent course is weakened by the Siberian high in winter. The Pacific coast course is weakened by the North Pacific anticyclone in summer, and this course is most evident in spring (in the East China Sea) and autumn (in the Pacific Ocean). The Japan Sea course is evident throughout the year.

3) Double-cyclones were classified into three types. Each of them is composed by: (Type 1) a Japan Sea cyclone and a Pacific coast cyclone, (Type 2) a Continent cyclone and a Pacific coast cyclone, and (Type 3) a Japan Sea cyclone and a cyclone on an occluded point of the Japan Sea cyclone.

4) Japan Sea cyclones of Type 1 are formed in the Japan Sea, and Pacific coast cyclones are formed in the East China Sea. Continent cyclones of Type 2 originate in the west, outside of the study area, and the Pacific coast cyclones are formed on the ocean along 30°N. Japan Sea cyclones of Type 3 are not formed in the Japan Sea, but in the western part of the study area.

5) Double-cyclones frequently occur in spring and infrequently occur in summer. This feature is not directly connected with the number of cyclones in each season. In summer, low frequencies of occurrence and genesis of the Pacific coast cyclones mostly preclude the existence of Types 1 and 2. In winter, the low frequency of the Continent cyclones also preclude Type 2. In autumn, Types 1 and 2 are infrequent, because the frequency maxima of occurrence and genesis of the Pacific coast cyclones are situated in the east of Japan.

Acknowledgement

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