A SYNOPTIC CLIMATOLOGICAL STUDY OF COLD FRONTS AND COLD FRONTAL PRECIPITATION OVER JAPAN

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Abstract The purpose of this study is to clarify the regional and seasonal features of cold fronts and cold frontal precipitation over the Japanese Islands. The annual total number of cold fronts passing there amounts to 158 per year. The regionality of distribution of cold frontal precipitation is first caused by the predominance of warm, wet air mass. Second, it depends on the variation of cold frontal Cu due to orographic effects. Third, it results from being warmer of cold air mass due to lee effects. Models of the passing cold fronts were given.

1. Introduction

In Japan which lies on the mid-latitude eastern coast of the Eurasian Continent, precipitation is caused by several factors: polar (*e.g.* Maejima, 1954), temperate (*e.g.* Yoshino, 1955) and tropical (*e.g.* Sekiguti, 1965). In addition, orographic effect complicates the phenomena of precipitation. As a result, it is important to examine the precipitation features according to its controlling factors in and around Japan.

Despite the development of the meteorological studies about the life process of cold front (*e.g.* Fujita, 1951, 1955; Hobbs, 1978; Muraki, 1978; Hitsuma, 1979), few synoptic climatological studies about it have been made. In the synoptic climatology which deals with "the integration of daily weather", cold fronts with precipitation are one of the most essential factors, since fronts can be treated as a repeated factor of weather pattern.

The purpose of the present study is to clarify the regional and seasonal features of cold fronts and cold frontal precipitation in Japan including its surrounding area. In this paper a large part of the author's doctoral dissertation will be summarized, except the discussion about geographical or time-space distribution of cold fronts and squall lines (Yamakawa, 1984).

The seasonal and regional reviews of the Japan's climate, which have been published by Fukui (1977), Yazawa (1980) and Maejima (1980), will hereafter contain the present researches on cold front and cold frontal precipitation.

2. Occurrence Frequency of Cold Front Passing over Japan

Purpose and methods

It is essential to examine the passing frequency of front before cold frontal precipitation is analyzed, since it helps us to know the extent of frontal influence and learn some fundamental regional features.

In this section, the passing frequency of cold fronts is surveyed across 140°E where fronts are vital. First of all, the region is divided (Fig. 1), by taking into account the predominant cyclone tracks and the location of observational stations of surface wind direction which indicates the passage of cold front.

The boundary between C and D is the line linking Wajima with Sendai. The boundary between D and E is the line linking Tanega-shima with Chichi-jima.

The track of front is classified based on both the center point of cyclone and the location of the southwestern margin of cold front. For example, when a cyclone passes across Hokkaido (the northern island of Japan) and the margin of the cold front passes between Hachijo-jima and Chichi-jima, it is identified as type BE. Accordingly, the cold fronts in question include some occluded fronts.

In this section, surface weather charts (09, 21JST = 00, 12GMT) are used for the five years (1976–1980).

Results and considerations

The annual total number of cold fronts passing around Japan amounts to 157.6 per year. In other words, cold front passes once in 2.3 days, if its seasonal variation is left out of account.

The greatest number of monthly mean frequency of cold fronts is recored in April and May; namely, fronts pass on half days of the months. The next highest frequency occurs in October and November. Not a few cold fronts pass also in January, February and March. On the contrary, only a few pass in July and August.

The types of DE, DF and EF, which are associated with the cyclones passing along the southern coast of Japan, amount to 59% of the annual total cases and are respectively counted about 20 days per the year.

Further, the high frequency is observed in the types of AB, AC and AD, that is to say, the cold front passing over Northern Japan or along the southern coast of Japan, associated with a cyclone passing north of Japan. Each of these types occurs at the rate of about 10 days in a year, showing the occurrence frequency 20% of all the cases.

The seasonal features of each frontal track are as follows: type DE often appear in the warmer season, mainly in June, but types DF and EF often appear in the colder season. Types AB, AC and CD most frequently appear in autumn, mainly in September and October, followed by spring.

Figure 2 shows the adjusted monthly frequency (isopleth) of passing cold fronts by tracks. In colder season the greatest number of frequency appear in the E and F region. Cold fronts pass at the rate of 8 per month or 2 per week, that is on an average, at intervals of 3 or 4 days. In April frontal activity become notable widely from north to south. It suggests that coupled cyclones tend to simultaneously pass along the Pacific coast of Japan and over

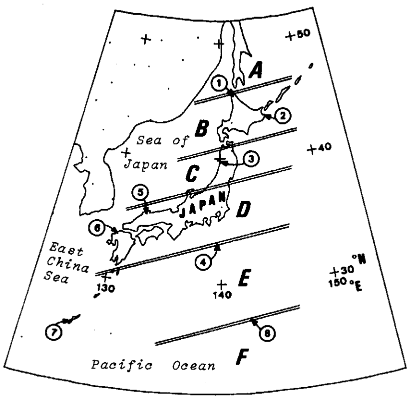


Fig. 1 Geographical map of Japan and its surrounding area, and regional division (A-F) for counting the occurrence frequency of fronts. Names of the stations with number (①-⑧) are shown in Fig. 11.

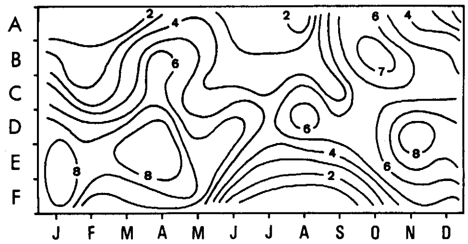


Fig. 2 Isopleth of occurrence frequency per month of cold fronts (1976–1980) counted according to their courses.

the Sea of Japan.

Cold frontal tracks, concentrated on the lower latitudes in May, shift northward in June and July with gradually decreased number of frequency. In summer they are extremely reduced not only over the sea to the south but also in Hokkaido and the area north of it. This is partly because cold air is not sufficiently accumulated, and partly because the frontal direction is turned nearly east-west. In this study, when both a cyclonic center and the southern edge of the cold front belong to the same domain (B, C, D, E), the frontal system is regarded as a stationary front with a small wave and left out of account.

In late summer cold frontal zone shifts southward. It stagnates in early autumn and causes the rainy season "*Shurin*". In October the frequency is higher in Northern Japan. It can be assumed that cyclones pass separately in the northern and southern area and some anticyclonic belts appear between them.

3. Synoptic Analysis of Cold Frontal Precipitation over Japan

Chosen cold fronts

In order to divide the seasons objectively, we have classified air masses on the basis of equivalent potential temperature. This division is based on its occurrence frequency at 850mb level.

The chosen cases are 35 cold fronts that passed over the Japanese Islands during the period of about seven years (Jan. 1973–March 1980). Among them, 5 passed over the whole area of Japan, 19 over Central and Southern Japan, and 11 over Northern Japan.

Table 1 shows the main features of each case. Notes for Table 1 are as follows:

1) "Date" is the day when equivalent potential temperature (θe) is recorded.

2) cf. Yamakawa, 1981; Table 2.

3) cf. Figure 1. A$'$ is the case where a cyclonic center passes the north of 50°N. A# is the

Table 1 List of the chosen cold fronts

No.	Date 1)	Season 2)	Surface: Passing Area	Surface: Passing Position 3)	850mb: θ_e (K) Warm Air	850mb: θ_e (K) Cold Air 4)	850mb: Strike 5)	850mb: Moving Speed (m/sec) 6)	850mb: NW-wind Speed (m/sec) 7)
1	21 Nov. '77	Autumn	All Over Japan	A F	* 311	284	S W	8	15
2	21 Oct. '79	Autumn		A E	323	286	S W	17	20
3	24 Nov. '73	Winter		A F	307	268	S W	20	25
4	9 Mar. '77	Winter		A F	* 312	274	S W	17	15
5	30 July '74	Summer		B E	* 345	330	WSW	8	3
6	16 Nov. '73	Autumn	Central and Southern Japan	A#E	310	287	S W	23	13
7	21 Nov. '74	Autumn		B F	317	285	SSW	20	20
8	3 Oct. '76	Autumn		B E	* 317	290	S W	8	13
9	28 Dec. '73	Winter		B F	299	272	S W	17	25
10	23 Feb. '74	Winter		B E	305	266	WSW	20	23
11	31 Oct. '76	Winter		B E	309	274	S W	17	20
12	26 Nov. '76	Winter		B E	* 305	269	SSW	11	23
13	14 Feb. '73	Spring		B F	302	277	S W	20	18
14	5 Apr. '74	Spring		B E	311	292	S W	23	5
15	1 May '74	Spring		B E	314	292	S W	14	10
16	6 Apr. '75	Spring		B E	317	292	SSW	17	20
17	2 Apr. '76	Spring		A#E	300	277	SSW	17	10
18	16 Apr. '78	Spring		B E	* 313	287	S W	8	18
19	7 Aug. '74	Summer		B E	342	322	WSW	14	5
20	16 July '75	Summer		B E	339	336	S W	11	8
21	8 Sep. '75	Summer		B E	342	313	S W	23	3
22	12 Sep. '75	Summer		B E	* 342	309	WSW	8	13
23	5 Aug. '77	Summer		B E	* 333	322	S W	8	10
24	15 Sep. '79	Summer		B E	* 334	312	WSW	8	10
25	15 Oct. '74	Autumn	Northern Japan	A'D	* 302	272	S W	11	18
26	6 Oct. '76	Autumn		A'C	300	283	S W	14	15
27	15 Oct. '77	Autumn		A'D	* 313	281	SSW	11	25
28	25 Nov. '74	Winter		A'D	* 290	272	S W	20	20
29	31 Dec. '79	Winter		A D	* 287	266	S W	14	20
30	26 Feb. '80	Winter		A E	* 290	263	S W	14	18
31	1 Apr. '77	Spring		A D	* 292	280	SSW	11	13
32	23 Apr. '77	Spring		A D	* 308	291	SSW	17	15
33	27 July '76	Summer		A C	* 346	324	WSW	5	8
34	23 Aug. '78	Summer		A C	337	310	S W	14	20
35	22 Sep. '79	Summer		A'D	* 336	292	S W	14	15

case where an occuluded point passes the domain B. The front marked No. 5 is treated as one of the instances belonging to the category of "all over Japan", since the cyclone in this case passes through Northernmost Hokkaido.

4) The value of θe with the sign * was recorded at 21JST, while the other at 09JST.

5) The strike (running direction) of cold front was measured in 32°–37°N for Central and Southern Japan, and in 40°–45°N for Northern Japan.

6) The speed of the moving cold front was measured along 37°N for Central and Southern Japan, and along 45°N for Northern Japan. The value (m/sec) was converted from the moving distance for 24 hours.

7) The maximum wind speed was measured within 1000km west of the cold front at 850mb level. The value is approximate, since it was estimated by the weather chart. The same location for 6) was applied.

Distribution of occurrence frequency of cold frontal precipitation

Figure 3 (autumn, winter and spring) and Figure 4 (summer) show the percentage of occurrence frequency of cold frontal precipitation (≧1mm). In Figure 3 We have dealt with 12 cases for Northern Japan and 17 for Central and Southern Japan; in Figure 4, 4 for the former and 7 for the latter.

The features of distribution in Figure 3 can be described as follows: 1) The higher frequency area is the region along the Sea of Japan, especially around the Shakotan Peninsula, Akita, Sakata and Matsue, where the precipitation (≧1mm) is registered in all the cases. 2) The next highest frequency (about 50%) is shown in Westernmost Japan and around

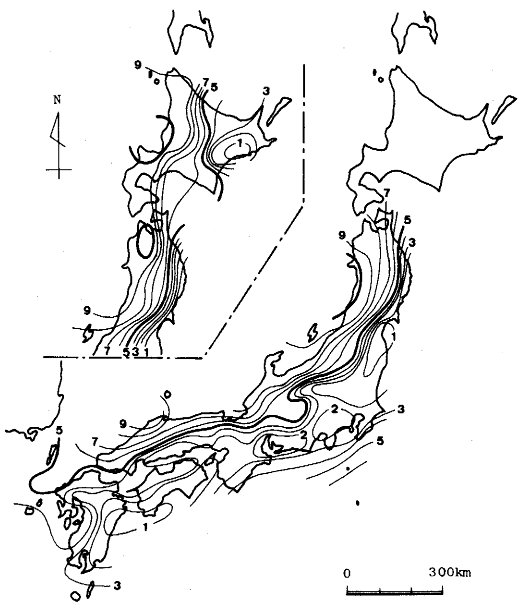


Fig. 3 Distribution of occurrence frequency (x10%) of cold frontal precipitation (≧1mm) in autumn, winter and spring

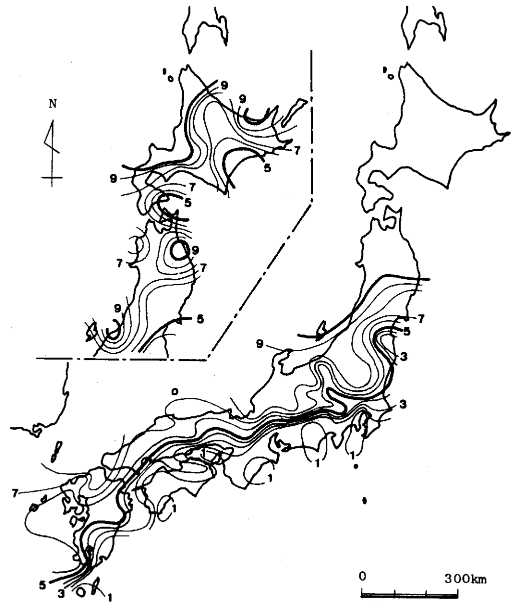


Fig. 4 Distribution of occurrence frequency (x10%) of cold frontal precipitation (≧1mm) in summer

the Izu Islands to the south of Southeastern Japan. 3) The lowest frequency, on the contrary, is recorded in the southeastern plains of the Main Island and the Pacific coast of Southwestern Japan. 4) The zone with a steep gradient of frequency occurs on the eastern side of the main divide of the Japanese mountain ranges. It shifts farther toward the Pacific coast than that of snowfall due to the winter monsoon (*e.g.* Kawamura, 1964).

Next, the features in summer (Fig. 4) can be summarized as follows: 1) In Northeastern Hokkaido and the northeastern district of the Main Island, the frequency is considerably high, in contrast with the lower frequency in the other seasons. 2) On the contrary, Takada and Fukaura show the lower frequency than in the other seasons. 3) The frequency around the Izu Islands is low, as is different from the cases in the other seasons.

Factors affecting the distributional contrast of cold frontal precipitation

Working hypothesis

The most pronounced characteristic of the distribution of cold frontal precipitation is a sharp contrast between the Japan Sea side and the Pacific side of Japan. The purpose in this section is to make clear the factors affecting the distribution. Here we mention a working hypothesis which consists of the following items:

[1] Cold frontal precipitation is apt to occur in the area with stronger SW or WSW air stream along the south of cold front, but seldom occurs in the area where the air stream is weakened.

[2] Cold frontal precipitation tends to occur on the northwestern side of the mountains, which dam up cold frontal Cu or Cb, while it rarely occurs on the southeast side.

[3] The cold air mass accompanied by a cold front is gradually transformed (heated and dried) on the lee side of the mountains, so that the cold front is weakened and causes only a little precipitation.

Regional differences in the warm air advection

We examine the category [1] of the working hypothesis, i.e. the relation between the strength of warm air stream and the precipitational distribution.

The cold front passing on 30–31 October 1976 (Yamakawa, 1981; Fig. 7) has been treated as a typical example of case studies. Over the Pacific side the 850mb maximum wind speed appears after the passage of a cold frontal surface at each station. On the contrary, the 850mb warm and wet air mass flows into the Japan Sea side at a wind speed over 20m/sec just before the passage of the front. This leads to heavy rainfall on this side.

Besides, the statistical survey shows that the regions where stronger ($\geq$20m/sec) southwesterly (wind direction: 180° to 270°) air stream are predominant (Fig. 5-a) correspond to those where cold frontal precipitation occurs with a higher frequency (Fig. 3).

When a cold front moves toward Northern Japan, the cold frontal Cu over the Sea of Japan is weakened, because the SW air stream is deformed by the mountains in Korean Peninsula. The cold front on 26 February 1980 (Fig. 6-a) shows a typical variation of cloud. The cloud band was shortened at 09JST on 26 February and then extended southwestward at 21JST on the same day when the warm, wet air mass flew through the Korean Channel.

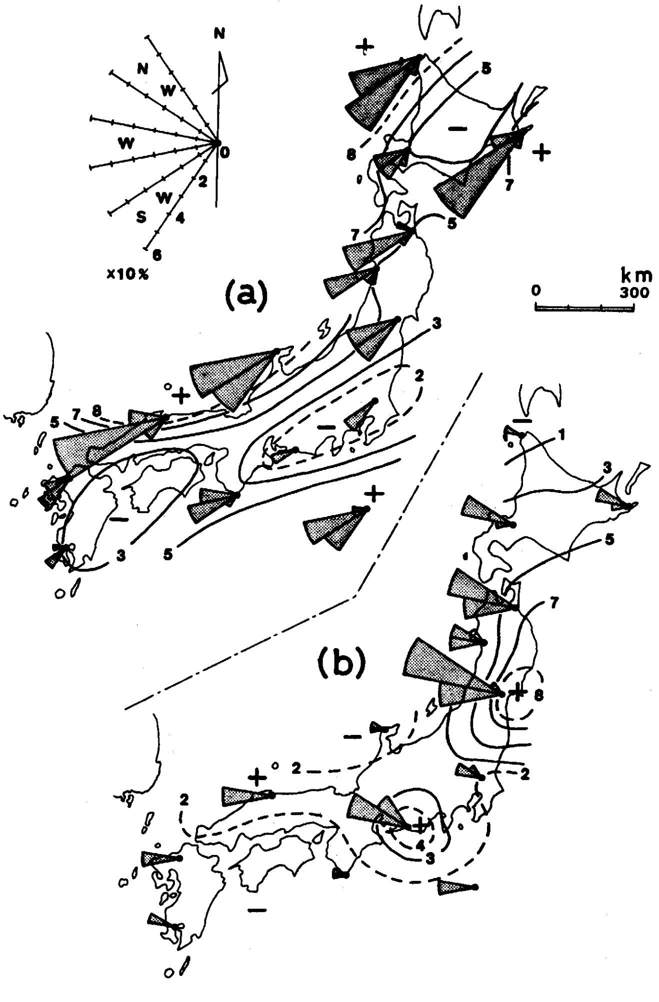


Fig. 5 Occurrence frequency (x10%) and wind roses of wind speed more than 20m/sec at 850mb level according to southerly (a) and northerly (b) components. These values are on the basis of 12 cases for Northern Japan (north of Akita) and 17 for Central and Southern Japan (south of Sendai), excluding the cases for summer.

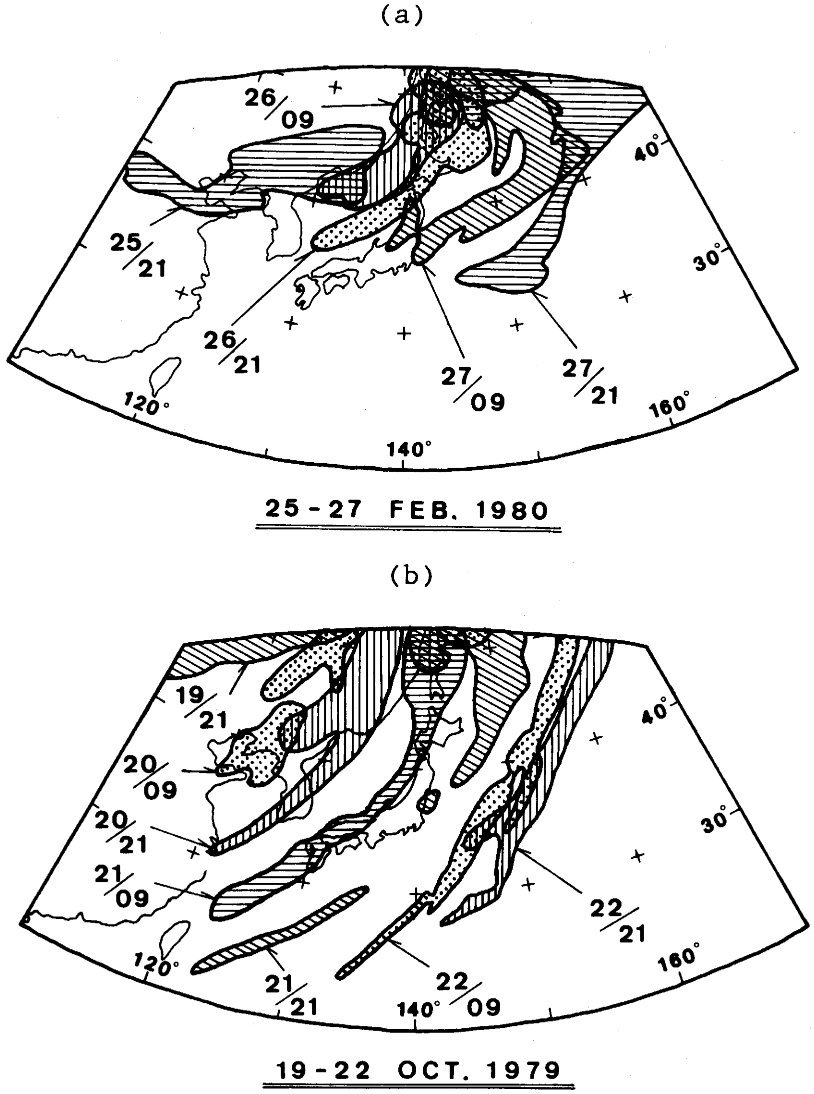


Fig. 6 Changes (day/JST) of frontal cloud systems around Japan. These composite maps are based on the nephanalysis charts drawn by the Meteorological Satellite Center.

Orographic effects on the variation of cold frontal Cu

We investigate the category [2], i.e. the relation between the damming up cold frontal Cu or Cb by mountains and the precipitational distribution induced by it. Since the GMS cloud pictures are the most convincing method to verify the above relation, the composite nethanalysis maps can be used for the present examination.

First, the residual phenomena of cold frontal Cu, as in Figure 6, can be found in all the cases, though there are differences in degree according to circumstances. For example, the colder air mass is, the more clouds remain there. Regionally, such residual clouds are most likely to remain on the Japan Sea side of the northern part of the Main Island.

The cold front on 19–22 October 1979 (Fig. 6-b) is a typical example where a cloud band is cut off while passing over Japan. The cloud band, which streched about 3000km from Sakhalin through the Japan Sea side to the East China Sea at 09JST on 21 October, was separated into northern and southern parts at 21JST on the same day while passing over the Main Island. The separated cloud bands, however, joined with each other again about 400km off the Pacific coast of Southeastern Japan at 09JST on 22 October.

The varying patterns of the cold frontal cloud system across Japan are represented as separation (mentioned above), dispersion, slimming, etc. Despite these differences case by case, it can be pointed out from abroad viewpoint that Cu is weakened for a while.

Regional differences in modification of cold air

We examine the category [3], i.e. the extent to which the cold air mass is transformed while passing over the Japanese Islands. The mean value (solid line) and the standard deviation (circle) of 850mb temperature when northwesterly (wind direction: 270° to 360°) wind speed reaches its maximum after the passage of the front (Fig. 7).

First of all, the distribution of the mean values shows that it is warmer by 1° to 3°C on the Pacific side than on the Japan Sea side in the same latitudes. Secondly, on the Pacific side the standard deviations (4.3° to 6.9°C) are greater by 1° to 3°C than on the Japan Sea side in the same latitudes.

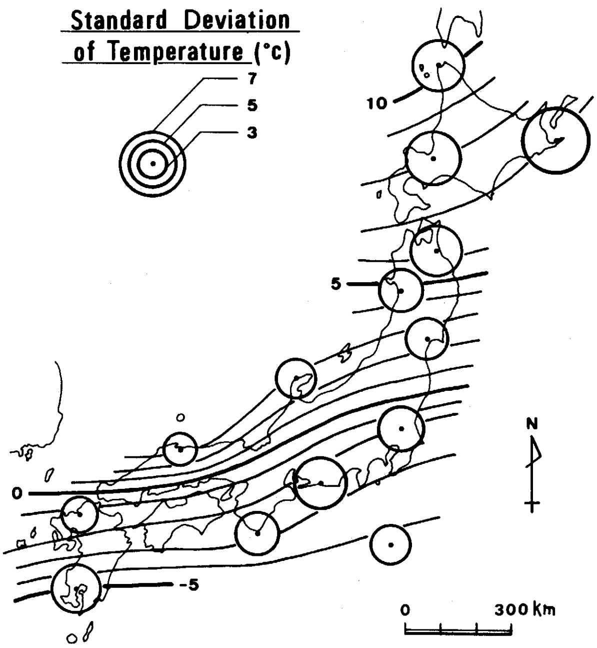


Fig. 7 Mean value (solid line) and standard deviation (circle) of temperature (°C) when NW wind at 850mb level is predominant after cold fronts pass. The based instances are same as in Fig. 5.

(a)

21JST, 30 Oct. 1976

(b)

21JST, 31 Oct. 1976

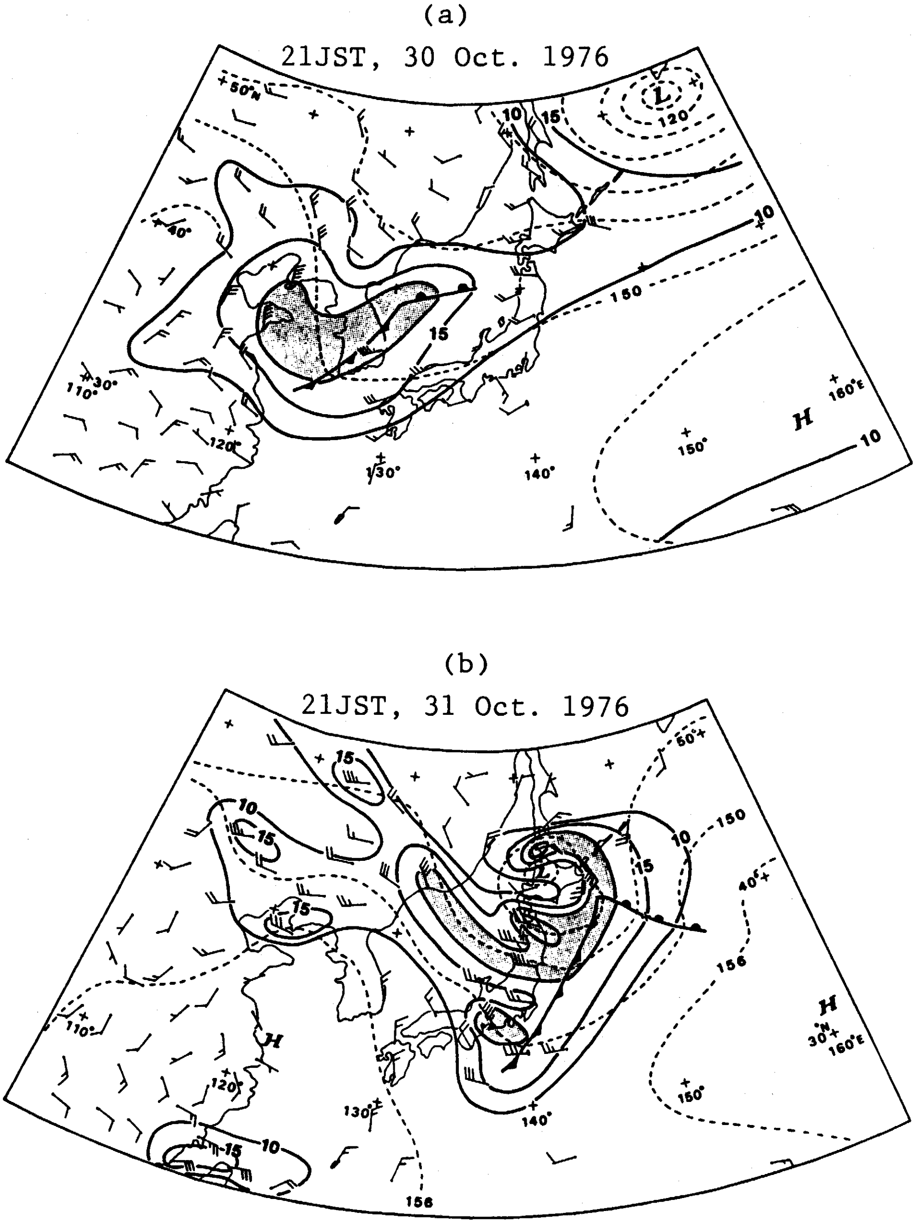


Fig. 8 Weather charts at 850mb level. Broken lines and solid lines show hight (x10gpm) and wind speed (m/sec), respectively. Hatching areas show more than 20m/sec.

These results suggest that the cold air frequently causes Föhn phenomena on the Pacific lee side, where the air descends after the passage of cold front.

From the results obtained by the case studies, it is shown that Föhn phenomena, in which temperature does not decrease but sometimes increase just after the passage of cold front, are apt to occur at Hamamatsu, Kagoshima and Tateno (in the order of higher frequency); the occurrence frequency ranging from about 50% to about 25%.

A typical case was observed on 31 October 1976 (Yamakawa, 1981; Fig. 7). The temperature on the Pacific side dropped in a small degree as the NW or WNW wind blew after the passage of the cold front (Tateno: –0.1°C/12hrs, Hamamatsu: –2.9°C/12hrs). At the same time, a drying up of the descending air appeared with the relative humidity lower than 50% (at 21JST on 31 October; Tateno: 24%, Hamamatsu: 45%). This proves the occurrence of Föhn phenomena.

Generalization

The category [1] is a primary one and is most important in determining the greater part of cold frontal air situations and weather. The category [2] and [3] are of the secondary and tertiary importance, respectively. The category [2] is in no way inferior to [1] as a factor of the weather (the existence or nonexistence of precipitation, etc.). The category [3] is local, but this factor, which additionally conditions the regional situations of air, cannot be ignored.

Cold frontal precipitation in the Izu Islands

In the Izu Islands, the occurrence frequency of cold frontal precipitation is about 50% (Fig. 3). Only warm air mass prevails and cold air mass does not (Fig. 5), because they are located in the lee of mountains of Central Japan. This means that precipitation was apparently stimulated by the factor as stated in the category [1], but weakened by the factor in the category [2].

To examine the cause and effect in detail, we again deal with the case of 30–31 October 1976. At that time a considerable amount of rainfall was observed also in the Izu Islands (Oshima: 0.0mm, Miyake-jima: 10.0mm, Hachijo-jima: 7.0mm). Figure 8 shows 850mb weather charts at 21JST on 30 October and at 21JST on 31 October. The hatched area shows the wind speed over 20m/sec. During this period the front moved eastward at a speed of 52.5km/h (14.6m/sec).

It is noted that the wind speed in the cold air mass is greater than the moving speed of the cold front. Then, the cold air mass under the frontal surface caused a downward stream. As a results, also the warm air mass over the frontal surface descended its slope (*cf.* Sansom, 1951; kata-front). In the lower or surface boundary layer, W wind blew even inside the frontal warm sector. Besides, between the W wind and the SW wind on the southeast of it, there occurred a pre-frontal squall, causing a strong thunderstorm in Hachijo-jima and Miyake-jima, 6 or 7 hours before the main front passed.

In this case, as the cold air mass was predominant, the front was originally kata-frontal type. In addition, the orographic effect caused to intensify kata-frontal character. The cross section analyses have been given by Yamakawa (1980-a).

The moving speed of a front and the maximum northwesterly wind speed in the cold air mass are shown in Table 1, as compared with the amount of precipitation in the Izu Islands. When much rain falls there, the wind speed is greater than the frontal speed; when the wind speed is greater, much rainfall is recorded in most cases.

The development of pre-frontal squall is due to both the frontal feature (primary factor) and the orographic effect (secondary factor).

Models of cold fronts passing over Central Japan

Summarizing the above-stated discussion, we will represent cross section models in Central Japan. The cold fronts can be classified into three types: predominant warm air type, predominant cold air type and unstable warm air type (Yamakawa, 1980-b, 1981). We will consider the weather features along the typical fronts when they lie on the Japan Sea side and on the Pacific side of Central Japan.

In figure 9 and 10, the surface and low-level wind is shown by the cross sections from northwest to southeast, but the upper wind is shown by the sections from west to east; namely these sections are vertically warped. J1 is jet stream with southerly component and J2 jet stream with northerly component. J3 is low-level jet or strong ascending air current and J4 strong descending air current.

Predominant warm air type

A typical phenomenon of this type (Fig. 9) occurred during the summer half year. Near the southern marginal part of the cold front ① that causes precipitation while passing over Japan, warm and wet air stream prevails. In most cases, the wind with a speed more than 20m/sec occurs in the warm sector at 850mb level. In particular, on the Japan Sea side of the Japanese Islands, the SW or WSW wind tends to be intensified continuously, because the front and the wind direction run nearly parallel to the mountain ridges.

In Figure 9 (a), the intensified SW or WSW wind causes a strong ascending air current J3 near the frontal surface and results in considerable amount of precipitation on the Japan Sea side.

In Figure 9 (b), the wind with increased southerly component under the orographic control blows into the surface boundary layer on the Japan Sea side and causes to maintain the strong ascending air current, though the cold front has arrived in the Pacific side. On the Pacific side, the cold frontal Cu are weakened and reduced by several factors. Besides, the temperature (°C) (drawn with broken lines) gradient of the lower atmosphere in Figure 9 (b) is smaller than in (a).

Predominant cold air type

A typical phenomenon of this type (Fig. 10) occurred on 31 Oct. 1976. It occurs when the NW wind, with a higher speed at 850mb level than the moving speed of front, prevails in a wide area.

In Figure 10 (a) the kata-frontal features are more or less developed. The low-level jet J3 in the warm sector is weaker and the Cu clouds are less developed than in the case of the predominant warm air type, so that the amount of cold frontal precipitation is rather smaller.

At the stage shown in Figure 10 (b), the kata-frontal features become marked on the Pacific side. As the cold air moves downward, the warm air over the frontal surface moves downward, so that the clouds mostly disappear. However, in the region several hundred km away from the Japanese Islands (for example, in the southern Izu Islands), the pre-frontal squall ② develops. On the Pacific side a noted drop of temperature is observed 1 or 2 days after the passage of the main front.

In the Japan Sea side, on the contrary, the cold air goes downward and the secondary front ③ appears between the warmer air and the fresh colder air mass, and then the bad weather continues. Besides, in the wintertime the group of Cu is produced in the trans-

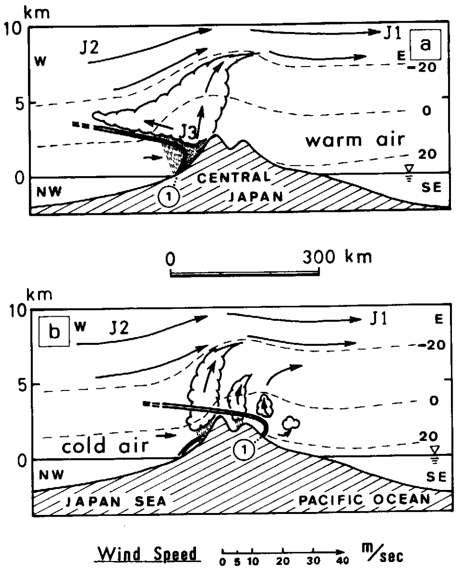


Fig. 9 Model of a cold front of the predominant warm air type. (For symbols, see the text)

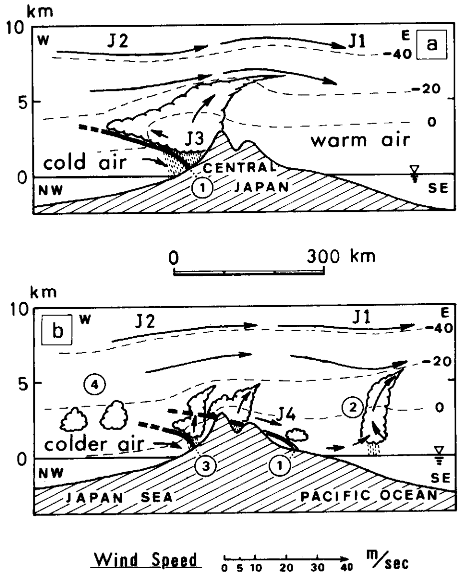


Fig. 10 Model of a cold front of the predominant cold air type. (For symbols, see the text)

formed Siberian cold air mass.

4. Proportion of Cold Frontal Precipitation at Several Stations

Classification of the causes of precipitation

In this chapter we will review this study from the Euler's viewpoint. First, the methods for classifying the causes of precipitation will be noted from the synoptic-meteorological point of view.

Table 2 shows its classification based on the factors adopted in this study. The classification has been made on the basis of hourly precipitation and wind direction, surface weather charts (09, 21JST) and nephanalysis charts of GMS (03, 09, 15, 21JST).

A cold front has a severe horizontal shear. In this study the passage of a cold front has been defined as "the change of wind direction from SW to NW". The precipitation from the cloud band along the shear line is interpreted as cold frontal precipitation. As far as the relation between synoptic meteorological systems and the precipitation, Yamakawa (1981) has reported.

Choice of objective stations

In order to ascertain the regional variation of precipitation characteristics, eight stations standing for the different regions have been chosen.

The objective stations are as follows: Wakkanai, Nemuro, Akita, Hachijo-jime, Matsue, Fukuoka, Naha and Chichi-jima. Wakkanai, Akita and Matsue stand for the features on the Japan Sea side where cold frontal precipitation very frequently occurs. At Fukuoka, though

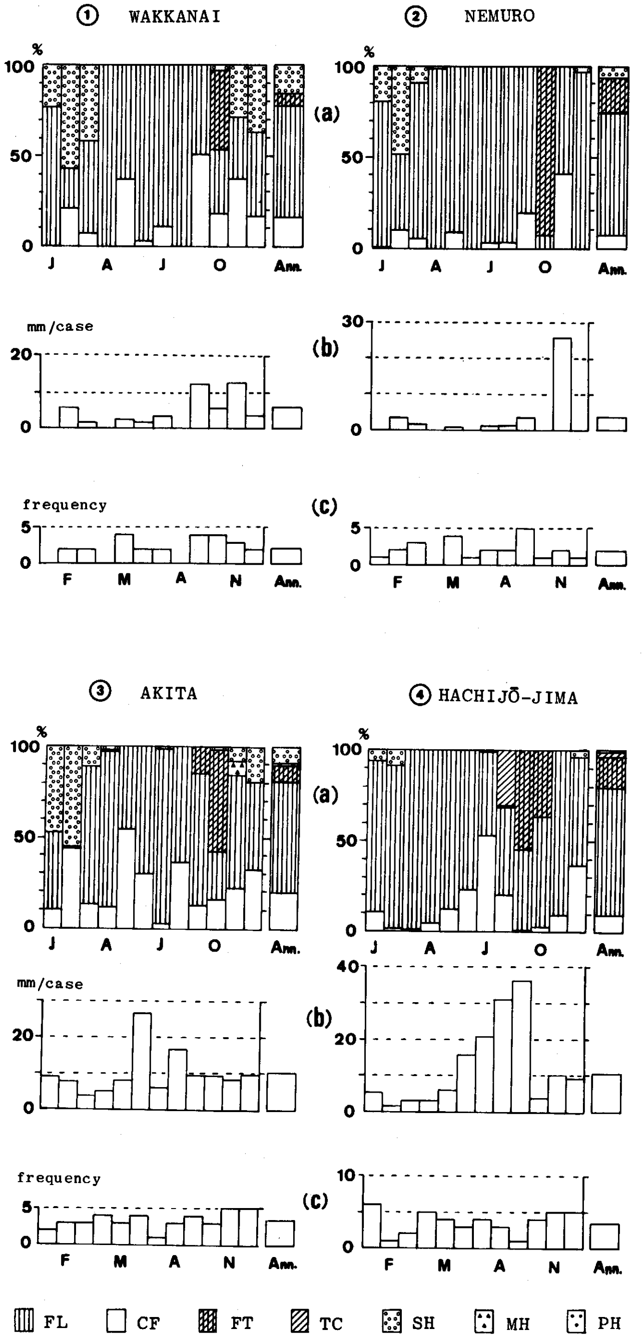
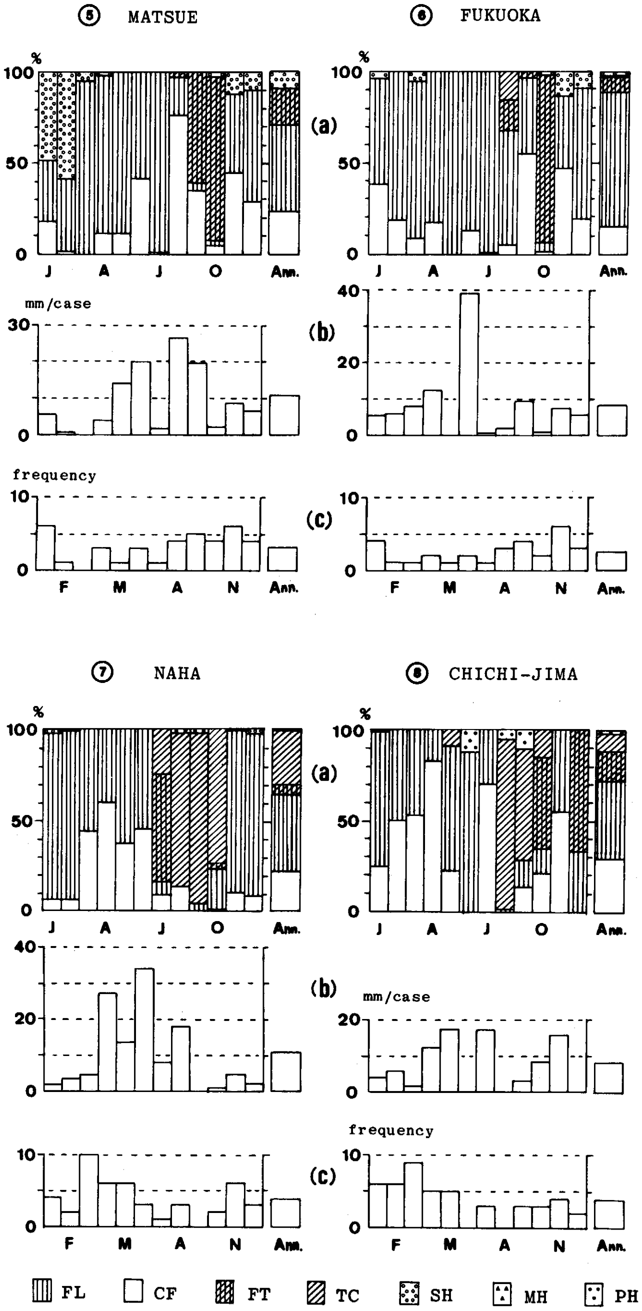


Fig. 11 (a) Monthly and annual proportions of cold frontal precipitation to total precipitation by its causes.
(b) Mean amount per case of cold frontal precipitation (≧1mm).
(c) Passing frequency of cold fronts with precipitation (≧1mm).



⑤ MATSUE
⑥ FUKUOKA
⑦ NAHA
⑧ CHICHI-JIMA
%
100
50
0
(a)
J A J O Ann.
mm/case
30
20
40
(b)
frequency
10
(c)
F M A N Ann.
FL
CF
FT
TC
SH
MH
PH

Table 2 Classification of synoptic factors causing precipitation

Scale of Disturbance	Synoptic Factor Causing Precipitation		Symbol
Synoptic Scale	Polar Front or Arctic Front	Front or Extratropical Cyclone except Cold Front	FL
Synoptic Scale	Polar Front or Arctic Front	Cold Front	CF
Synoptic Scale	Polar Front or Arctic Front / Tropical Cyclone (including Typhoon)	Interaction of Front and Tropical Cyclone	FT
Synoptic Scale	Tropical Cyclone (including Typhoon)	Tropical Cyclone	TC
Synoptic Scale	Disturbance inside Anticyclone	Cumulus Clouds inside Siberian High (with Winter Monsoon)	SH
Sub-synoptic Scale	Disturbance inside Anticyclone	Meso-scale or Local Disturbance inside Migratory High	MH
Sub-synoptic Scale	Disturbance inside Anticyclone	Meso-scale or Local Disturbace inside North Pacific High	PH

situated on the Japan Sea side, it is rather difficult for the cold frontal precipitation to occur. Nemuro was chosen as a representative station of Northern Japan and the Pacific side. Hachijo-jima is a typical place where cold frontal precipitation occurs with an exceptionally high frequency even in Central Japan and the Pacific side. Yamakawa (1974) has noted the importance of cold fronts accompanied by the cyclones passing along the southern coast of Japanese Islands; here we will reexamine it by using the data of Naha and Chichi-jima.

Regional differences in the proportion of cold frontal precipitation to total precipitation

There are considerable regional differences in the proportion (or contributing percentage) of cold frontal precipitation to total precipitation. The features observed for a year (Apr. 1979–March 1980) will be discussed.

As can be inferred from the facts in Figure 3, the proportion is higher in the stations of the Japan Sea side. At Matsue (Fig. 11-⑤) it is 23.7% and at Akita (Fig. 11-③) 20.5%. It is noticeable that the cold frontal precipitation is about 2.5 times of the precipitation due to the winter monsoon in both stations (Matsue: 8.9%, Akita: 8.3%). The winter presure pattern of this year had certainly a tendency to be short-lived, but it was not unusual and was nearly normal.

At Fukuoka (Fig. 11-⑥) the proportion of the cold frontal precipitation is no more than 15.3%, which amounts to only about 2/3 of that at Matsue. This difference will be made clearer in the next section.

There is a larger difference between the two stations in Hokkaido. At Nemuro (Fig. 11-②) the proportion is 7.4%, whereas it is no less than 17.6% at Wakkanai (Fig. 11-①). This is probably because cold frontal Cu are frequently dammed up by the Hidaka mountain range and the Daisetsu mountains. It is worth noting that at Wakkanai and Nemuro the amount of cold frontal precipitation is almost similar to that due to the winter monsoon (Wakkanai: 16.0%, Nemuro: 6.2%).

At Hachijo-jima (Fig. 11-④) the annual cold frontal precipitation is 447.5mm, being the greatest value among the eight stations. However, the proportion of the cold frontal precipitation is only 9.8%, because of a large amount of precipitation caused by the other factors (*e.g.* the moving cyclones or stationary fronts around the Izu Islands).

On the contrary, at Naha (Fig. 11-⑦) the proportion amounts to 21.8%, showing the third greatest value among the eight stations; and at Chichi-jima (Fig. 11-⑧) it amounts to 28.8%, showing the greatest. The former is often under the influence of developing cold fronts; while the latter is often out of the influence of developed extratropical cyclones except cold front.

Regional differences in the mean value of cold frontal precipitation

Figure 11-b shows the mean value of cold frontal precipitation at each station. This value is the quotient of the total amount of precipitation divided by the number of passing cold fronts (Fig. 11-c).

The greatest value (10.8mm/case) is recorded at Matsue and Naha. The third greatest is 10.4mm/case at Akita and Hachijo-jima, where rather stronger cold fronts tend to pass. At Chichi-jima the value (8.3mm/case) is smaller than at Naha or Hachijo-jima, because cold fronts are approaching the core region of a subtropical anticyclone (Nakamura, 1976) which consists of the air mass with less water vapor, and because the cold air masses have been transformed as moving over the warm sea for a long time.

At Fukuoka the value (8.2mm/case) is smaller than at Matsue. This may be attributed to the fact that the Korean Peninsula dams up the cold frontal Cu moving over there.

The small values, 6.1mm/case at Wakkanai and 3.8mm/case at Nemuro, certainly result from the reduced temperature and water vapor of the warm air mass. Here again, it should be pointed out that the water vapor amount has a great influence on the cold frontal precipitation.

5. Conclusion

Summarizing the results obtained in this paper which are considered as of climatologically greatest importance:

(1) In the Ogasawara Islands and the Southwestern Islands, the passing frequency of cold fronts is higher than in any other parts of Japan and its surroundings. In the former the annual proportion of frequency of cold frontal precipitation amounts to the value of the highest rank, and in the latter the intensity is in the first rank.

(2) In the Japanese Islands there are some regional features in occurrence frequency, intensity and annual proportion of cold frontal precipitation to total precipitation. In each

of these respects, greater values are recorded in the region of the Sea of Japan.

(3) Though Akita and Matsue are widely supposed to receive much precipitation due to the winter monsoon, the cold frontal precipitation reachs 2 or 3 times of it. From the fact, the cold frontal precipitation is considered to be important water resources.

(4) The regionality of distribution of cold frontal precipitation is first caused by the predominance of warm, wet air mass which leads to supply much water vapor and generate ascending air currents.

(5) Second, it depends on the change of cold frontal Cu due to orographic effects. Third, it results from the variation in temperature of cold air mass due to the lee effects.

(6) Around the Izu Islands a pre-frontal squall tends to occur when the NW wind prevails in the rear sector of a cold front.

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