CLIMATOLOGICAL STUDY OF COLD FRONTAL PRECIPITATION IN JAPAN

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Abstract Cold frontal precipitation in Japan has regional and seasonal characteristics. First of all, a cold front and its precipitation have been recognized. The contributing rates of cold frontal precipitation due to various causes have been surveyed at 11 stations. The annual or seasonal occurrence frequencies of precipitation due to cold fronts, classified by equivalent potential temperature (850mb), have been studied at about 140 stations. In addition, on the basis of analyzing the aerological data and meso-scale phenomena, pre-frontal or post-frontal squalls, thunderstorms, upper or lower winds related to them, etc. have been examined. Last of all, various models of the cold frontal system have been illustrated on the basis of the acquired information.

1. Introduction

Recently various comprehensive reports about the climate of Japan have been published (Fukui, 1977; Yazawa, 1980; Maejima, 1980; Yoshino, 1980). As has been mentioned in them, the snowfall in winter and the heavy rain by Bai-u front or typhoon have been very actively studied.

Now, from a somewhat different point of view, the causes of precipitation in Japan are arranged as follows:

(1) Extratropical cyclone and front (including intermediate scale disturbance).

(2) Tropical cyclone (including the tropical cyclone accompanied by front with coupling cloud system).

(3) Group of cumuli due to winter monsoon.

(4) Sub-synoptic (meso or cumulous) scale disturbance within anticyclonic sphere.

The cold frontal precipitation, included in (1), is expected to amount to almost as much as that due to (2) or (3) in the annual total of some regions (Chapter 3).

The purposes of this study are to understand the contribution of cold frontal precipitation to the annual precipitation in some selected stations, and to clarify its regional and seasonal characteristics in Japan. Cold fronts occur repeatedly and comprise weather patterns. Therefore, the analysis of cold frontal precipitation is also included in synoptic climatology dealing with the accumulation of daily weather phenomena.

2. Recognition of Cold Front and its Precipitation

Cold front

Because cold frontal activity is an aspect of the heat exchange between high and low latitudes, its basic characteristics should be determined by the air-masses on both sides of a cold front, namely the cold air-mass on the north and the warm air-mass on the south, which affect the features of cold frontal precipitation to a considerable degree. Then, the cold fronts just before they enter the Japanese Islands, have been classified on the basis of the equivalent potential temperature (θ_e) on the 850mb surface of the cold or warm air-masses (Fig. 2). For the index stations Vladivostok in the cold air-mass and Hachijo-jima in the warm air-mass have been chosen, but in the case where a front passes through Northern Japan, Ust'Tyrma in the former and Misawa in the latter have been adopted (Fig. 1).

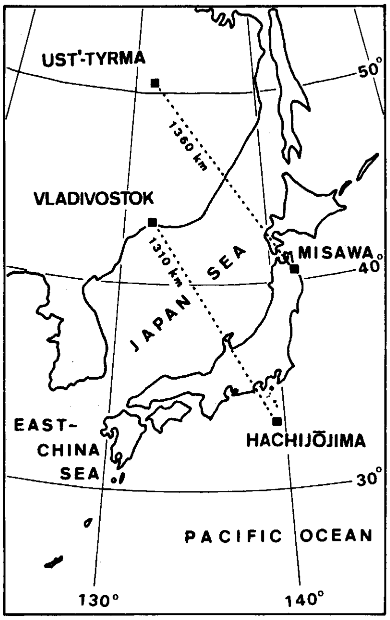
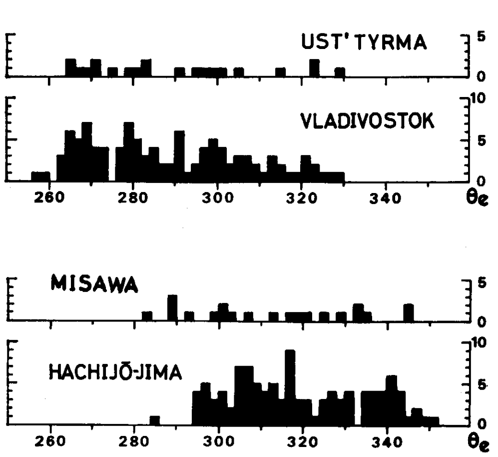


Fig. 1 Index stations of determining air-masses, distances between the stations, and names of regions written in this paper



Polar Air Mass	Middle-latitude Air Mass	Tropical Air Mass	
~ 275	276 ~ 330	331 ~ °K	θe

Fig. 2 Distribution frequency of θ_e (850mb) in the cold or warm air masses and classification of air-masses

Concerning the 127 cold fronts, the air-masses have been divided into *polar air-mass* (P), *middle-latitude air-mass* (M), and *tropical air-mass* (T) (Fig. 2). Then, the front belongs to the category of winter when the cold air-mass is P and the warm air-mass is M; it belongs to that of spring or autumn when both air-masses are M; and it belongs to that of summer when the former is M and the latter is T. From the cold fronts that passed over Japan for 6 years (1973 ~ 1978) 10 cases in each season, 40 cases in all, have been chosen. The dates and θ_e of the cold or warm air-masses in the respective cases have been arranged in Table 1.

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".

Table 1 Dates and θ_e of cold or warm air-masses in each case (* shows the cold front passing over Northern Japan)

SPRING		θ_e (°K)		SUMMER		θ_e (°K)	
(JST) Time	Date	Warm Air	Cold Air	(JST) Time	Date	Warm Air	Cold Air
09	14 Feb. '73	302	277	21	11 July '73	332	327
09	5 Apr. '74	311	292	*21	30 July '74	345	330
09	1 May '74	314	292	09	7 Aug. '74	342	322
21	26 May '74	326	302	*09	14 Aug. '74	335	324
09	6 Apr. '75	317	292	09	16 July '75	339	336
09	2 Apr. '76	300	277	09	8 Sep. '75	342	313
21	1 Apr. '77	308	277	21	12 Sep. '75	342	309
*21	23 Apr. '77	308	291	*21	27 July '76	346	324
09	9 Apr. '78	310	283	21	5 Aug. '77	333	322
21	16 Apr. '78	313	287	*09	23 Aug. '78	337	310

AUTUMN		θ_e (°K)		WINTER		θ_e (°K)	
(JST) Time	Date	Warm Air	Cold Air	(JST) Time	Date	Warm Air	Cold Air
09	16 Nov. '73	310	287	09	24 Nov. '73	307	268
09	15 Sep. '74	322	302	09	28 Dec. '73	299	272
21	15 Oct. '74	318	286	09	23 Feb. '74	305	266
09	21 Nov. '74	317	285	*21	25 Nov. '74	290	272
09	24 Oct. '75	315	306	*21	8 Mar. '76	289	266
21	4 Oct. '76	317	290	09	31 Oct. '76	309	274
*09	6 Oct. '76	300	283	21	26 Nov. '76	305	269
09	8 Nov. '76	317	280	09	15 Dec. '76	295	270
*21	15 Oct. '77	313	281	21	18 Dec. '76	306	265
21	21 Nov. '77	311	284	21	9 Mar. '77	312	274

Cold frontal precipitation

The precipitation from the cloud bands along the shear line has been interpreted as cold frontal precipitation. By means of the surface weather charts every 3 hours and the daily original registers of meteorological observation, the cause of each rainfall has been probed at 140 stations all over Japan, and the starting and finishing times of the cold frontal precipitation have been determined and then the amount of the precipitation has been calculated.

In the stations where the center of an extratropical cyclone passes to the north within a few hundred km, if there is an interruption in precipitation or if the hourly precipitation reaches a minimum between the warm front and the cold front as the wind changes direction (from SW to NW), then these two types of precipitation can be distinguished. Of course, in the stations where a cyclone passes to the north farther than a few hundred km, the cold frontal precipitation is expected.

In this study, the pre-frontal squall due to the instability line and the post-frontal squall due to the secondary front are included in the cold frontal precipitation. On the other hand, precipitation due to some causes unrelated to the cold front should be excepted.

Precipitation due to winter monsoon

It is well known that the Japan Sea side of Japan has much snow due to the changing in quality of the Siberian air-mass in winter.

The features that we find useful in distinguishing the precipitation due to the winter monsoon from any other precipitation are as follows. First of all, after a cyclone passes eastward, the interruption or minimum amount of the precipitation can very often be recognized. In addition, the Siberian high has its center over the continent above 40°N, and the atmospheric pressure at sea-level of the station under study is more than 1000mb as standard.

3. Contributing Rate of Cold Frontal Precipitation

In order to know the contributing rate of the cold frontal precipitation to the annual or monthly amount of precipitation, Figure 3 has been drawn up using data from 11 stations in 1974. These data have been got on the basis of hourly precipitation referred to weather charts (09JST, 21JST) and in some cases photographs by NOAA 4.

This year there were some unique cases such as the rather longer stay of the Bai-u front, but there was no large deviation of the precipitation at any stations. Ogawa (1977) has reported the distributions of fronts in 1974 which are worth comparing.

Wakkanai

The cold frontal precipitation occurs in autumn, because the North Pacific anticyclone becomes weak and cold fronts move southward. The annual rate is only slightly above 1%, in contrast to the rate due to the winter monsoon (about 20%), because the warm, wet air-mass along a cold front is hard to flow over.

Nemuro

The cold frontal precipitation is as little as that due to the winter monsoon. This is generally the case with the Pacific side of Eastern Japan.

Akita

The cold frontal precipitation does not occur in early summer, but the amounts increase in the other seasons, mainly in October, so that the annual rate amounts to nearly 20% and it is not so much different from the precipitation due to the winter monsoon (23%).

Miyako

The annual rate is as low as 4%. The difference from that in Akita is surely caused by the orographic controls. In summer the cold frontal precipitation occasionally occurs, because the passing cold front is apt to cause heat-frontal thunderstorms.

Wajima

There is a tendency similar to that observable in Akita, but the amounts due to (1) (2) (4) in Chapter 1 at Wajima are respectively greater than at Akita.

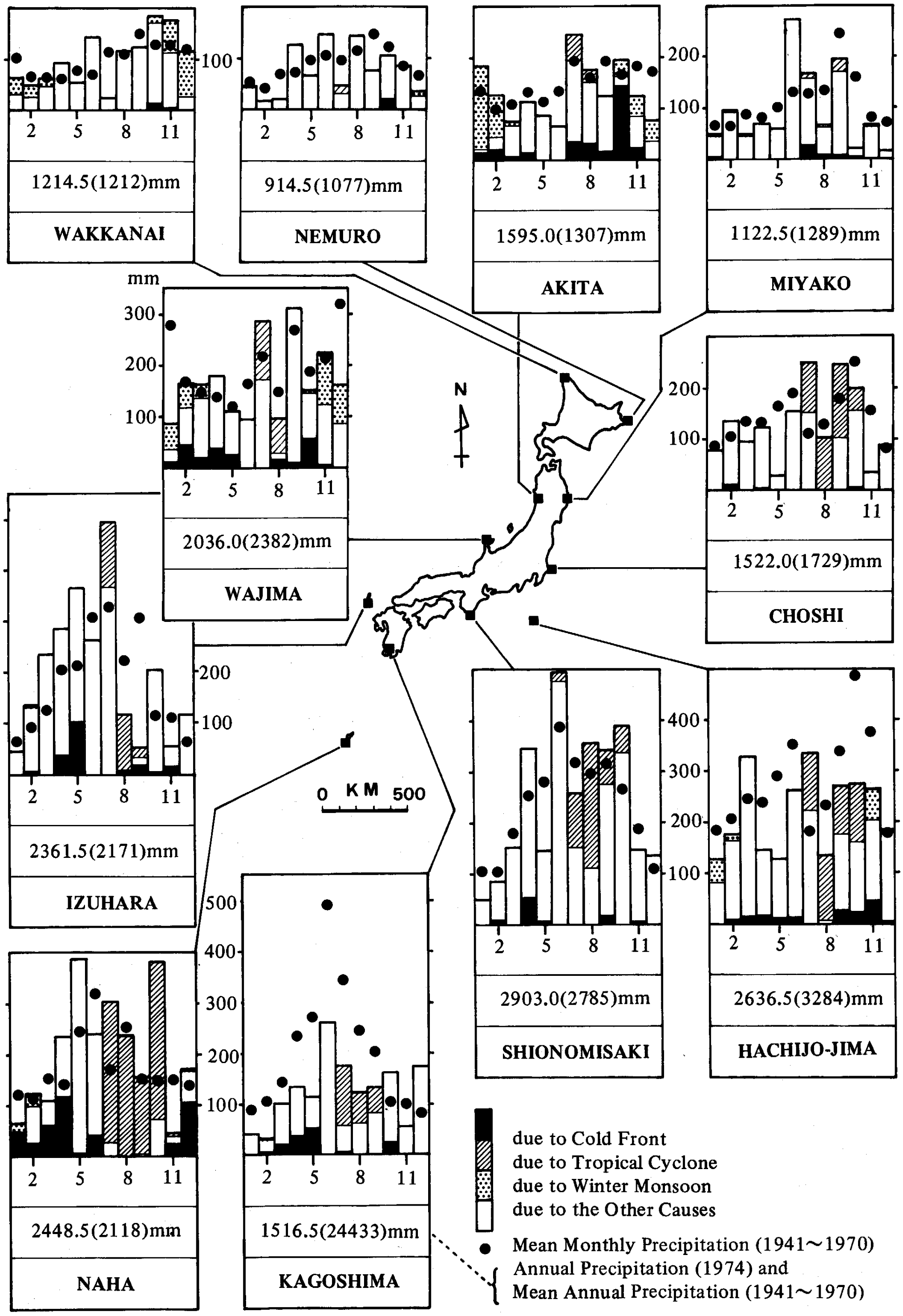


Fig. 3 Monthly precipitation (1974) classified by synoptic causes at the selected stations

Choshi

The slight cold frontal precipitation appears only in spring and autumn, and the annual rate is less than 1% the least in all the stations. The cold frontal precipitation is greatest in autumn (16% in November), but the annual rate is less than 10%, for the centers of cyclones pass very often in the neighborhood.

Hachijo-jima

As far as a normal year it rains most abundantly in autumn, mainly because the influence of polar fronts (shu-rin) and typhoons, partly because the passage of cold fronts.

Shionomisaki

Since the rate due to cold fronts amounts to 15% in April, the annual rate becomes 3%, but in many points it resembles the case in Choshi.

Izuhara

The cold frontal precipitation is great in spring and autumn, and especially in May when the rate amounts to 28% due to 'May storms'. Though precipitation due to winter monsoon seldom occurs, the annual rate due to cold fronts amounts to about 10%, so that Izuhara belongs to another type, different from the type of Akita and Wajima.

Kagoshima

The rate in May amounts to 28% as in the case of Izuhara. From late winter to early summer the rate is higher and the annual rate (10%) is not different from the rate influenced by tropical cyclones (15%), whose annual increase or decrease is greater.

Naha

The cold frontal precipitation occurs from November to July, in other words during the period except summer and early autumn. When the Siberian air-mass overflows remarkably in winter, the monthly rate reaches a minimum (February in 1974, but January in a normal year), but as a whole the precipitation due to the passing of the polar fronts is notable in the cold half year. The annual rate is strongly controlled by typhoon, but in either case the Nansei (Southwestern) Islands including Naha perhaps has the highest rate all over Japan.

4. Occurrence Frequency of Cold Frontal Precipitation

Choice of objects

The criteria adopted when the objects of this study were chosen are as follows: 1) The cold front has been analyzed on the surface weather chart drawn by the Forecast Department of the Japan Meteorological Agency. 2) When the cold front passes, the wind change can be clearly observed at many stations. 3) At any station the cold frontal precipitation is 5mm or more. 4) The cold front passes without stopping. 5) There is no wave cyclone on the cold front before its passage over Japan. 6) The cold front is not a part of coupled cyclone (one passes through the Japan Sea and the other passes along the southern coast of Japan).

Annual frequency

The occurrence frequency of the cold frontal precipitation, which is 0mm or more and 5mm or more, has been illustrated in two figures (Fig. 4a, 4b). They represent a pronounced contrast between both sides of the central mountain range in the Japanese Islands. However, the distribution pattern of the frequency is not as marked as that of precipitation due to winter monsoon (Suzuki, 1962; Kawamura, 1964), and the steep-gradient area of the occurrence frequency of the cold frontal precipitation shifts more or less toward the Pacific coast. The author is of the opinion that the high frequency area of 5mm or more and the low frequency area of 0mm or more respectively correspond to the frequent occurring areas of "anafront" and "katafront", which Bergeron (1937) pointed out for the first time and Sansom (1951) investigated in detail in England.

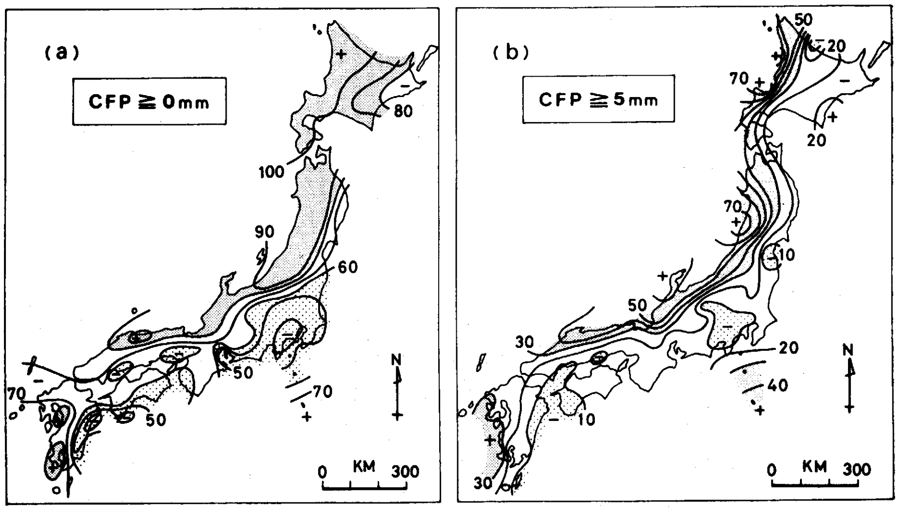


Fig. 4 Annual occurrence frequency (%) of cold frontal precipitation (CFP)

Frequency of each season

The occurrence frequency of the cold frontal precipitation which is 5mm or over has been drawn about every four seasons (Fig. 5).

First of all, in regard to the case in spring, autumn, and winter, the low rate in winter in the Kyushu district is conspicuous and a few differences according to the seasons are recognized, but the two high rate areas in the region facing the Japan Sea and in the environs of the Izu Islands, and the low rate zone between them are clearly differentiated.

The most characteristic distribution is seen in summer. As compared with the other seasons, the rate of the Izu Islands and its vicinity is lower, but the high rate area along the Japan Sea is wider and spreads over the mountains to the Pacific side of Eastern Japan.

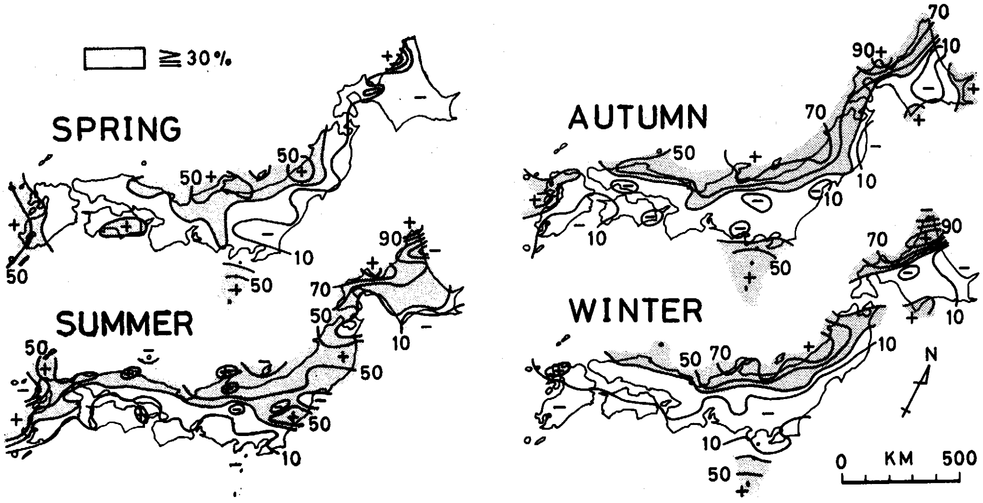


Fig. 5 Occurrence frequency (%) of cold frontal precipitation (≧5mm), according to seasons

5. Analyses of Lower Atmosphere

Case study

A few days around 31 Oct. 1976 are chosen as a typical instance (Fig. 6), and the special quality of the atmospheres is analyzed on the 850mb surface, where low level jet streams are apt to occur before or after cold fronts pass. The prosperity and decay of the jet will exert considerable influence on the cold frontal precipitation.

The wind isoplethes with two sections along the Japan Sea and along the Pacific Ocean have been made, adding the different amounts of temperature and relative humidity every 12 hours (Fig. 7). In this analysis the change from WSW to W of wind direction has been recognized as the passing of a cold frontal surface.

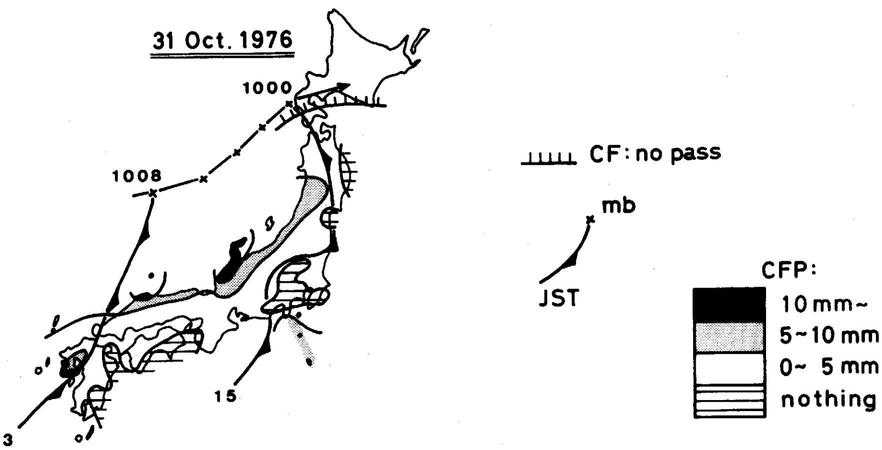


Fig. 6 Passing locations of cold fronts (CF) and distributions of cold frontal precipitation (CFP)

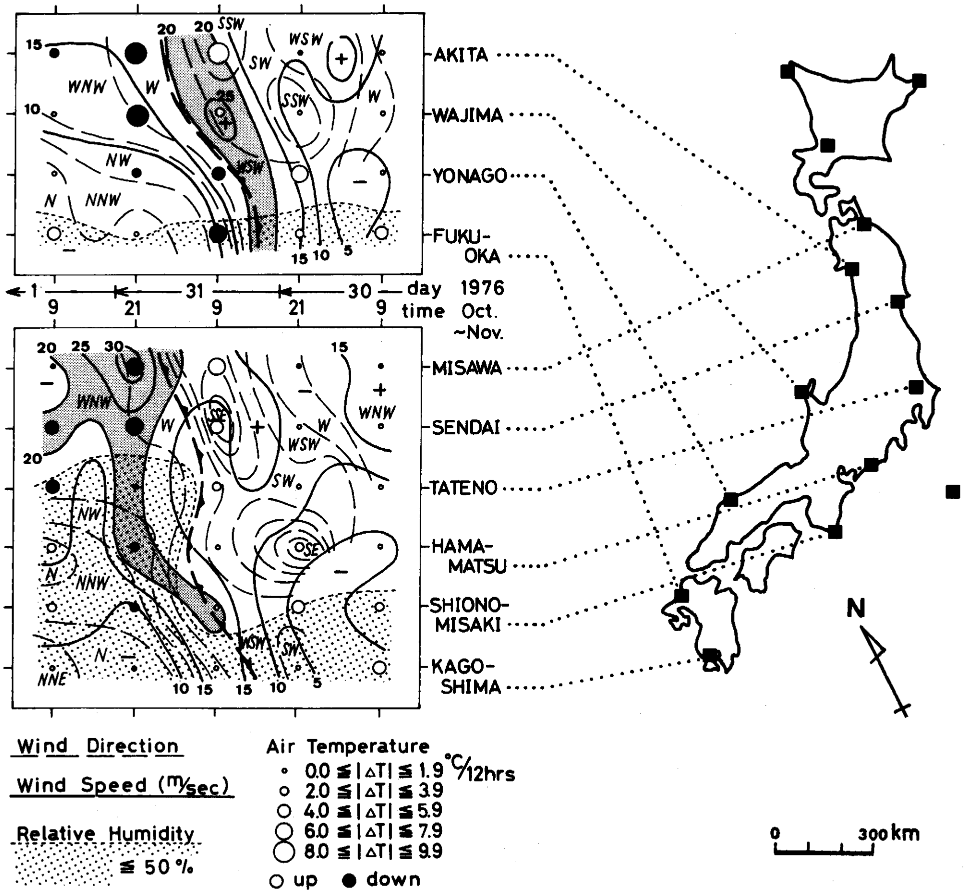


Fig. 7 Space and time analysis chart of atmosphere on 850mb surface, and the stations of upper air observation

It is a characteristic on the Japan Sea side that the SW hot, wet low level jet prevails (Wajima: 09JST, 31 Oct.: θ_e = 307°K, wind speed = 31m/sec). In contrast, on the Pacific Ocean side the NW cold, dry low level jet generally prevails (Tateno: 09JST, 31 Oct.: 292°K, 22m/sec).

Inductive characteristics of lower atmosphere

In order to comprehend inductively the prosperity and decay of the jet before or after a cold front passes, the maximum wind speeds classified by the components of south and north have been surveyed, and the occurrence frequency more than 20m/sec and their wind roses have been illustrated (Fig. 8).

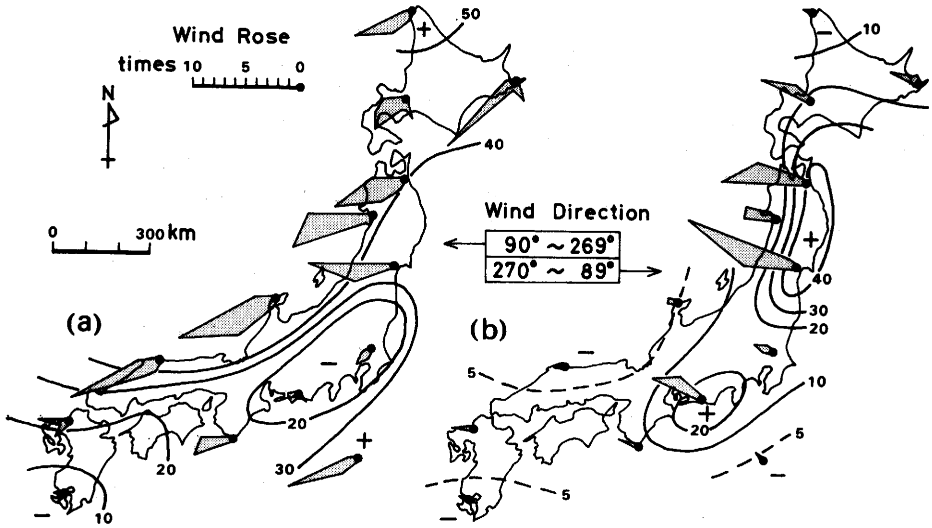


Fig. 8 Occurrence frequency (%) and wind roses of maximum wind speed ≧20m/sec classified by wind direction (850mb) before or after passing of cold front

6. System of Cold Front

Winter (spring, autumn)

In winter the system of typical cold front is illustrated (Fig. 9) when it exists in the area facing the Japan Sea (a) and in the area facing the Pacific Ocean (b). Lengths of the arrows are proportionate to wind speed. In spring and autumn this system is alike except 4.

1: Cold front

2: Pre-frontal squall due to the katavatic warm air from the frontal surface and the warmer, wetter air-mass (Omoto, 1965), namely, due to the pre-frontal waves (Eagleman, 1980)

3: Secondary front due to the fresh colder air-mass and the rather warmed air

4: Clouds (Cu) due to winter monsoon

J1: WSW upper jet stream

J2: WNW upper jet stream

J3: SW warm, wet low-level jet stream

J4: NW cold, dry low-level jet stream

Summer

In summer the system of a typical cold front is illustrated in Figure 10.

5: Thunderstorm (Cb) caused by E or SE warm, very wet advection

J5: WSW relatively weaker upper jet stream

J6: WNW relatively weaker upper jet stream

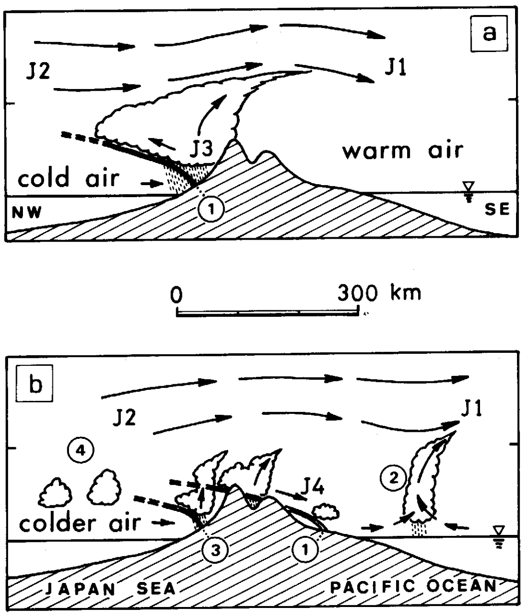


Fig. 9 System of a typical cold front in winter

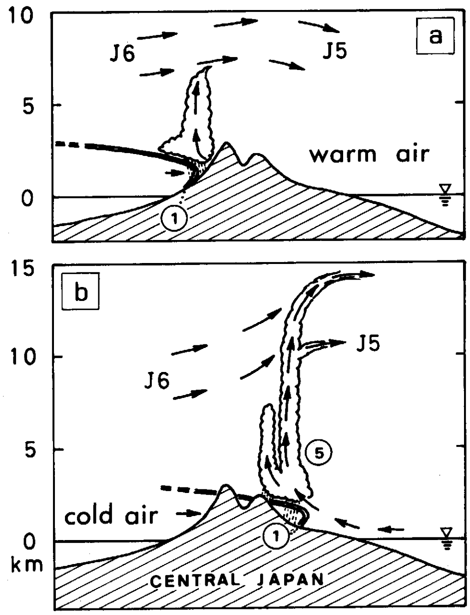


Fig. 10 System of a typical cold front in summer

7. Conclusion

Active cold frontal area

Roughly pseaking, this is the area of more than 30% in Figure 4b; the area facing the Japan Sea or the East-China Sea (including the Nansei Islands), and the southern part of the Izu Islands. In the typical cases the SW warm, wet low-level jet flows along the southern edge of the cold front. As a result, the precipitation intensity becomes greater and the occurrence frequency of 5mm or more is also higher.

In the northwestern side of Central Japan, it begins to rain a few hours, or just, before the passing of a cold front, and the precipitation duration tends to become longer because of the post-frontal squall caused by the secondary front. In the Izu Islands the precipitation intensity and duration tend to be respectively stronger and shorter because of the pre-frontal squall caused by the unstable convergence line.

From the viewpoint of water resources, the most important considerations are the precipitation due to the winter monsoon in the area facing the Japan Sea, and the precipitation due to tropical cyclones in the Nansei Islands, but the cold frontal precipitation is of secondary importance in both areas.

Unactive cold frontal area

This is the area of less than 60% in Figure 4a; most of the area facing the Pacific Ocean. A cold front is not active and the occurrence frequency of the precipitation is lower. Even if it rains, it does so only a little. The factors that cause such an unactive front are the damming up of cumuli by the mountain barriers, the infrequent inflow of the warm air-mass due to the presence of the masses of mountains, and the adiabatic heating of the cold air by the katabatic wind on the leeward side of the mountains.

Summer active cold frontal area

This is the area of more than 30% in Figure 5 (summer), which covers the greater part of Eastern Japan. Most of the part facing the Pacific Ocean in this area, though terms "low frequency areas" for the year, is "high frequency areas" as far as the summer is concerned. In summer the significant advection arises from the east or southeast to the mountains of Central Japan on the extra low-level (near the 900mb surface) before the passing of a front, and then thunder clouds appear. However, since the rainy area due to the thunderstorm is limited by its appearing position, moving direction, and life-span, rain is hardly observed in the Izu Islands and its environs. On the mountains in Central Japan it can also be pointed out that the front passes earlier in this case, though it generally passes later.

Acknowledgement

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