Synoptic-scale Climatology of Cold Frontal Precipitation Systems during the Passage over Central Japan

Hiroyuki Kusaka[1] and Haruka Kitahata[2]

[1]*Center for Computational Sciences, University of Tsukuba, Tsukuba, Japan*

[2]*Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Japan*

Abstract

The synoptic-scale climatology of cold frontal precipitation systems during the passage over central Japan was investigated for 19 years (1988–2006). Cold frontal precipitation events are classified into the following three types: Widespread, Hokuriku, and Jump type. Widespread-type events, which bring precipitation throughout Japan, mainly occur in spring and autumn, and the cyclones tend to move northeastward from the central part of the Sea of Japan. The central pressure of the Widespread-type cyclones is the deepest and this type has the most moisture out of the three types. Hokuriku-type events, which bring precipitation exclusively over the Hokuriku area often appear in winter, and the cyclones move eastward from the northern part of the Sea of Japan. As a result, the isobars form in an east-west orientation over mainland Japan as the cold front arrives in the Hokuriku area. The Hokuriku-type cyclones tend to be relatively weak and there is less moisture during the events. For the Jump-type events, in which the precipitation distribution appears as precipitation bands jumping over the Kanto area, cyclones develop rapidly due to the deep trough at the 500 hPa level, changing the isobars from east-to-west to northeast-to-southwest during the events.

1. Introduction

Japan is a mountainous country (Fig. 1); thus, a cold front produces complex precipitation patterns as it passes over the central Japanese mainland (Fig. 2) (e.g., Yamamoto 1984; Fujibe 1989; Mannoji and Kurihara 1993; Okamura and Kimura 2003; Seino et al. 2003). Such topography adds to the difficulty of accurately forecasting weather over the Kanto area, including the Tokyo metropolis. Climatologists and forecasters are concerned with precipitation patterns as cold fronts pass.

Many previous studies have introduced a typical case of the Jump phenomenon in which the precipitation distribution appears as precipitation bands jumping over the Kanto area, including the so-called "Kanto-Fukiage type" or "Uwasuberi type" (e.g., Hitsuma and Uesaka 1978; Muraki 1978; Hitsuma 1979; Hasegawa and Narikawa 1985; Mannoji and Kurihara 1993; Tsuchiya 1998). Climatological studies have also been conducted, although they are few in number (e.g., Yamakawa 1980; JMA 1992). The Japan Meteorological Agency (JMA) (1992) classified the cold frontal precipitation into two types: (i) that observed in the Kanto area and (ii) that with absence of precipitation over the plain. Furthermore, the JMA (1992) investigated the differences in the two types regarding temperature, wind, and pressure fields. Shoji (1991) also conducted composite analyses using a similar classification approach.

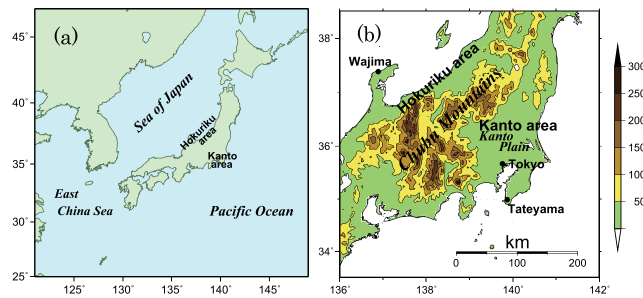

Fig. 1. (a) Geography around Japan and (b) geography of the central Japan.

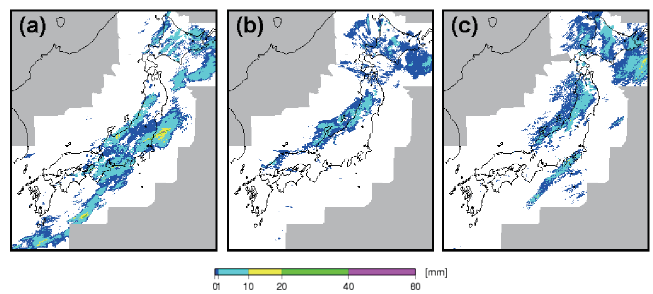

Fig. 2. An example of the (a) Widespread-type (at the middle of IN and OUT time), (b) Hokuriku-type (at OUT time), and (c) Jump-type events (at OUT time). Figures are derived from the Radar-AMeDAS data. Shadings indicate the hourly precipitation amount during the cold front passage over Japan.

In this study, we classify the second type that is classified by the JMA (1992) further into sub-categories on the basis of the precipitation patterns and then statistically investigate the associated synoptic environment to understand synoptic climatology of cold frontal precipitation systems during the passage over central Japan.

2. Methodology

A climatological survey of cold fronts passing over central Japan was performed for 19 years (1988–2006) using surface weather charts. The surface weather charts are provided by the JMA, which are twice daily (00 and 12 UTC) prior to March 1996 and four-times daily (00, 06, 12, and 18 UTC) after that. In this study, the precipitation events that meet the following three criteria are selected: (1) the cold front must pass over the Chubu Mountains and Hokuriku and Kanto areas; (2) it

Corresponding author: Hiroyuki Kusaka, Center for Computational Sciences, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8572, Japan. E-mail: kusaka@ccs.tsukuba.ac.jp.

must be associated with the “Nihonkai cyclone,” which is an extratropical cyclone passing over the Sea of Japan; and (3) other cyclones and cold fronts must be absent near the domain. Events that do not meet the above criteria (1)–(3) are excluded from the analysis. Finally, the events that meet the above criteria are classified into three categories based on the precipitation pattern from the Radar-AMeDAS analysis rainfall data which is estimated by meteorological radars and calibrated using surface rain gauge observations:

(1) Widespread: Precipitation bands move with the cold front and precipitation is observed throughout mainland Japan (Fig. 2a).
(2) Hokuriku: Only the Hokuriku area experiences precipitation (Fig. 2b).
(3) Jump: Precipitation occurs on the northwest side of the Chubu Mountains, but little precipitation is observed over the Kanto area. When the cold front reaches the Pacific Ocean, precipitation bands develop again (Fig. 2c). This includes the so-called Kanto Fukiage type, as called by weather forecasters.

The classification of the events is conducted subjectively.

In this study, we first investigate the occurrence frequency of each type. Secondly, the composites of the sea level pressure, the 700 hPa moisture, and the 500 hPa height fields are carried out for each type to investigate the features of the synoptic-scale environment. The 6-hourly JRA25 data with horizontal resolution of 1.25 degree (Onogi et al. 2007) are linearly interpolated onto 3-hourly data in the present study. All composites are based on the 3-hourly data. Lastly, we investigate the cyclone track of each type using the method proposed by Adachi and Kimura (2007).

3. Results

3.1 Occurrence frequency of each type

A total of 48 Widespread-, 57 Hokuriku-, and 14 Jump-type cold front events are selected from 228 events that meet the criteria (1)–(3), respectively. In advance of the composite analysis, the monthly occurrence frequency is investigated (Fig. 3). Widespread-type events tend to appear in spring (March–May) and in autumn (September–November) and represent 50% and 33% of the total occurrence, respectively. Hokuriku type events frequently occur in the winter season (December–February), with 61% of the total number of events occurring within these months. Jump-type events occur more frequently in late autumn to early spring.

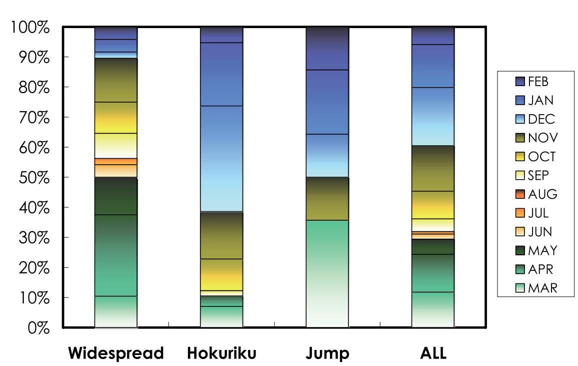

Fig. 3. Monthly occurrence frequency for each type. “ALL” means the total of the three types.

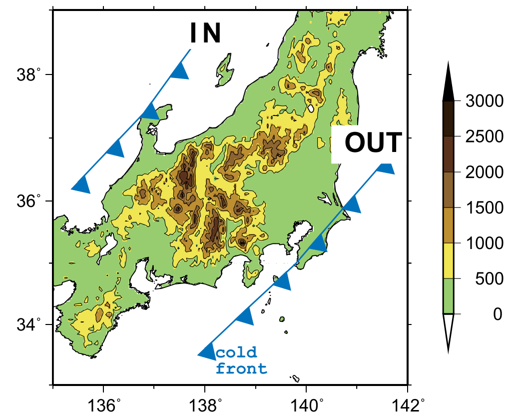

Fig. 4. Schematic of the definition of the IN and OUT times. IN and OUT identify the times when the cold front reaches the vicinity of the Wajima station (136.9°E, 37.4°N) and the Tateyama station (139.9°E, 35.0°N), respectively.

3.2 Synoptic-scale climatology of each precipitation type

In the present study, the IN and OUT times are subjectively defined at 3-hour intervals by following the method implemented by the JMA (1992). IN and OUT identify the times when the cold front reaches the vicinity of the Wajima station (136.9°E, 37.4°N) and the Tateyama station (139.9°E, 35.0°N), respectively (Fig. 4). The positions of the cyclones at the IN and OUT time are defined by the 3-hourly data. Then, we confirmed the positions of the cyclones using the surface weather chart by sight.

Figure 5 shows the composites of the sea level pressure created by the events identified as Widespread, Hokuriku, and Jump types. The Widespread-type has the lowest mean central pressure out of the three at the IN time (Table 1), which indicates that this type of cyclone tends to be relatively strong and well developed at the IN time (Fig. 5a). The low-pressure center is located over the central part of the Sea of Japan (136.25°E, 40.00°N), and has a deep surface trough which extends southward. As a result, the orientation of the isobar is northeast-southwest over the Kanto area. The cyclone tracks of a Widespread-type event (Fig. 6a) show that the cyclone tends to move northeastward over the Sea of Japan from the vicinity of the East China Sea.

For the Hokuriku type composite, the low-pressure center is located over the northern part of the Sea of Japan (140.00°E, 45.00°N) at the IN time (Fig. 5b), and has a shallow surface trough. As a result, the orientation of the isobar tends to be east-west over the Hokuriku and Kanto areas. These are the typical features of the Hokuriku-type cyclones at the IN time. Another typical feature is that the cyclone is not as strong as a cyclone in a Widespread-type event, as reported above. In addition, the cyclone tracks differ from those of the Widespread-type events. The cyclones tend to move

Table 1. The central pressure of the composite cyclones.

	IN	OUT	(OUT–IN)
Widespread	1002.3	1001.9	−0.4
Hokuriku	1006.3	1004.5	−1.8
Jump	1005.6	1002.1	−3.5

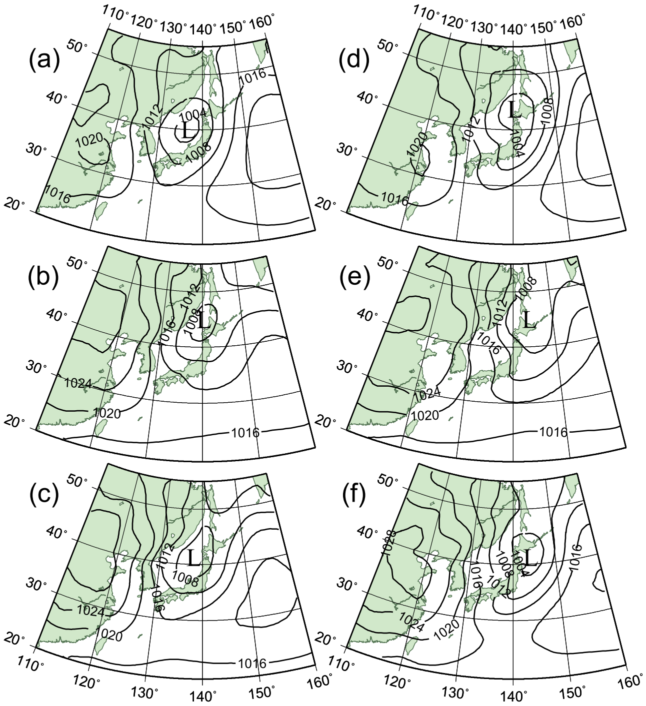

Fig. 5. Composites of the sea level pressure fields, created from the (a) Widespread-type, (b) Hokuriku-type, and (c) Jump-type events at IN time. (d), (e), and (f) are the same but at OUT time, respectively. The contour interval is 4 hPa. "L" indicates the location of the minimum central pressure of the cyclone.

eastward, primarily in the zone between 40°N and 50°N (Fig. 6b).

The low pressure center for the Jump type is similar to that for the Widespread type (137.50°E, 41.25°N) at the IN time (Fig. 5c). The cyclone develops from 1005.6 hPa to 1002.0 hPa on average (Table 1). This pressure development is an important feature of a cyclone with the precipitation pattern of a Jump-type event. Another key feature could be that the orientation of the isobar changes from east-west at the IN time to northeast-southwest at the OUT time (Table 2). The orientation of the isobar over the Kanto area is similar to that of a Hokuriku-type event at the IN time; however, it mimics that of a Widespread-type event at the OUT time.

The composites of the geopotential height at 500 hPa and the specific humidity at 700 hPa are depicted in Fig. 7. For a Hokuriku-type event, the pressure trough at the 500 hPa level is over the Sea of Japan at the IN time (Fig. 7b). In addition, the trough is shallower than

Table 2. The number of the cases that have the characteristic of the Jump type.

Rapidly development	6
East-west orientation of isobars at IN time over the Kanto Plain	11
Presence of a coastal front	12

that of a Widespread-type event. These results are consistent with the sea level pressure, which indicates that the cyclone is not as strong as a Widespread-type event. For a Jump-type event, the trough is over the western boundary of the Sea of Japan and west of the surface low-pressure center (Fig. 7c). The trough at the 500 hPa level is the deepest out of the three types, which causes the pronounced development of a low pressure system during the period.

Figure 7a indicates that there is a significant amount of moisture present for the Widespread type when compared to the other types. It could be considered that water vapor may be transported northward from the south of Japan and can be one of the causes of the widespread precipitation. On the other hand, the Hokuriku type has less moisture. The Jump type also has less moisture, although the amount present is slightly larger than the Hokuriku type. These specific features were found for each event despite the seasonal difference of the composite analysis (Supplement 4).

4. Conclusions

Widespread-type events tend to occur in the spring and autumn. The composite of the sea level pressure shows that the cyclone is located over the central part of the Sea of Japan and then moves northeastward. It is also noteworthy that the average central pressure is the lowest of the three types at the IN time. The composite of the specific humidity indicates that the Widespread type has the most moisture. These synoptic field features result in precipitation throughout mainland Japan.

Contrary to the Widespread-type events, the Hokuriku-type events occur in the wintertime, and there is less moisture in the atmosphere. Statistically, this type of cyclones are more likely to occur in the northern part of the Sea of Japan, which cause isobars in the east-west orientation over mainland Japan at the IN time. The results from the composite analyses indicate that the cyclones tend to be relatively weak for this type of events.

The most characteristic aspect of the Jump-type events is that the cyclone develops rapidly due to the deep trough at the 500 hPa level. As the cyclone passes

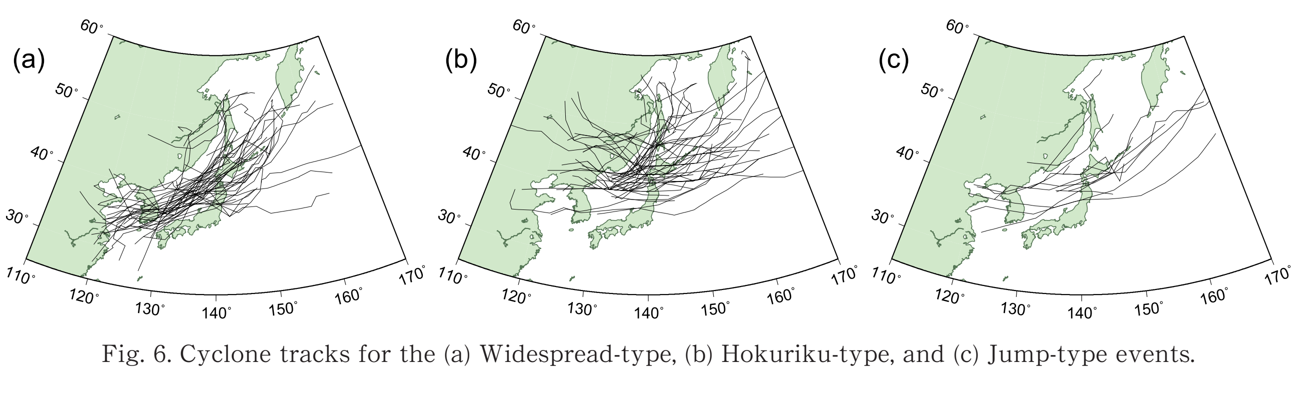

Fig. 6. Cyclone tracks for the (a) Widespread-type, (b) Hokuriku-type, and (c) Jump-type events.

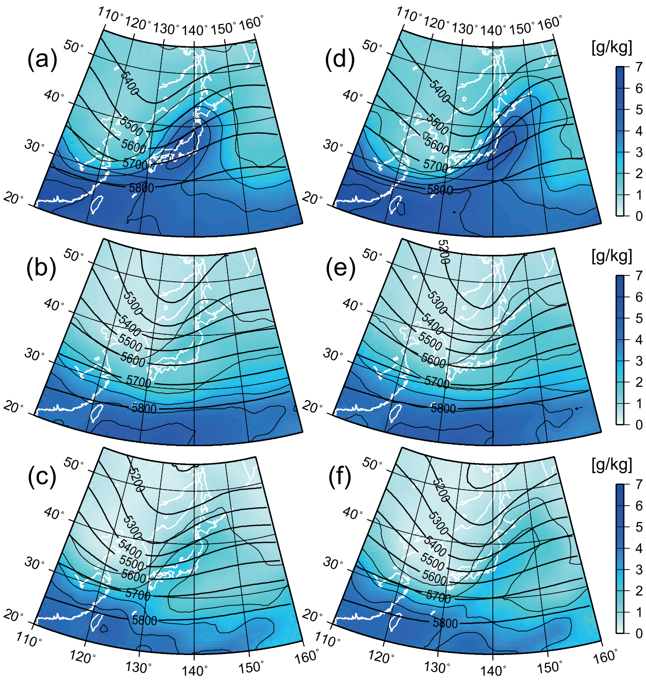

Fig. 7. Composites of the geopotential height at 500 hPa (thick lines) and the specific humidity at 700 hPa (color and thin lines), created from the (a) Widespread-type, (b) Hokuriku-type, and (c) Jump-type events at IN time. (d), (e), and (f) are the same but at OUT time. The contour interval is 100 m for the geopotential height, and 1 g kg^{-1} for the specific humidity.

over Japan, the orientation of the isobars changes from east-west to northeast-southwest statistically.

5. Remarks

The Hokuriku-type events have cyclones which are relatively weaker than a Widespread-type one, and the background has less moisture. These characteristics most likely prevent precipitation bands from traversing the Chubu Mountains.

According to the results of the composite analysis, the orientation of the isobars is east-west over the Kanto Plain at the IN time for a Jump-type event. This suggests that the area is covered by southwesterly winds, which can cause a coastal front (Fujibe 1990) in the southern Kanto Plain and a cold-air layer over the inland area. A coastal front is observed in 11 out of 14 Jump-type cases. It is possible that this results in little precipitation over the Kanto Plain.

As there is a large amount of case-to-case variability, further analyses will be needed to investigate the formation mechanism of the precipitation pattern. Numerical and observational studies are potential subjects for future studies.

Acknowledgements

The authors are grateful to Dr. Sachiho Adachi and Mr. Hiroki Kimura of the University of Tsukuba for the help with investigating cyclone tracks.

Supplements

An example of the Widespread-type, Hokuriku-type, and Jump-type events are shown in Supplement 1, 2, and 3, respectively. The composites of the specific humidity created from each type events in each season are shown in Supplement 4.

References

Adachi, S., and F. Kimura, 2007: A 36-year climatology of surface cyclogenesis in East Asia using high-resolution reanalysis data. *SOLA*, **3**, 113–116.

Fujibe, F., 1989: Short-term precipitation patterns in central Honshu, Japan – Classification with the fuzzy c-means method, *J. Meteor. Soc. Japan*, **67**, 967–983.

Fujibe, F., 1990: Climatology of the coastal front in the Kanto Plain. *Pap. Meteor. Geophys.*, **41**, 105–128.

Hasegawa, R., and J. Narikawa, 1985: The weather in the southern part of the Kanto district associated with Nihonkai low. *J. Meteor. Res.*, **37**, 299 – 314, (in Japanese).

Hitsuma, M., 1979: A view on jumping of rainband after retard at central Japan. *Tenki*, **26**, 329 – 333, (in Japanese).

Hitsuma, M., and K. Uesaka, 1978: Some case study on the use of surface wind and temperature data for rainfall forecasting. *J. Meteor. Res.*, **30**, 207–213, (in Japanese).

Japan Meteorological Agency, 1992: Weather condition during the cold front passage: Classification based on precipitation or non-precipitation on the Kanto Plain. *Technical News of the Tokyo District Meteor. Obs.*, **109**, 1–15, (in Japanese).

Mannoji, N., and K. Kurihara, 1993: Deformation of the cold front over the terrain of central Japan. *Tenki*, **40**, 513–523, (in Japanese).

Muraki, H., 1978: A behavior of a radar rainband associated with the cold front over the central part of Japan. *Tenki*, **25**, 723–730, (in Japanese).

Okamura, O., and F. Kimura, 2003: Behavior of GPS-derived precipitable water vapor in the mountain lee after the passage of a cold front, *Geophys. Res. Lett.*, **30**, 1746, doi:10.1029/2003GL017572.

Onogi, K., and co-authors, 2007: The JRA-25 reanalysis. *J. Meteor. Soc. Japan*, **85**, 369–432.

Seino, N., H. Yoshikado, F. Kobayashi, J. Sato, and Members of Tsukuba Area Precipitation Studies, 2003: Vertical structure of local fronts observed in Kanto, Japan. *J. Meteor. Soc. Japan*, **81**, 367–391.

Shoji, Y., 1991: Characteristics of surface wind on the southern part of the Kanto Plain during the cold front passage. *Technical News of the Tokyo District Meteor. Obs.*, **102**, 1–8, (in Japanese).

Tsuchiya, A., 1998: Characteristics of the cloud pattern and the rainfall area in Kanto area associated with passing cold front. *Technical Report of Meteor. Satellite Center*, **35**, 29–43, (in Japanese).

Yamakawa, S., 1980: A synoptic climatological study on cold frontal precipitation in Japan. *Geograph. Rev. Japan*, **53**, 574–588, (in Japanese).

Yamamoto, A., 1984: Meso-scale analysis in a front passing through the central Japan in Spring. *J. Meteor. Res.*, **36**, 1–14, (in Japanese).

Manuscript received 4 February 2009, accepted 2 April 2009
SOLA: http://www.jstage.jst.go.jp/browse/sola/