WEATHER SYSTEMS OF WINTER PASSING COLD FRONT OVER NORTH JAPAN

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Abstract A weather system before and after a cold front passage over North Japan is studied from the viewpoint of mesoscale and synoptic scale meteorology. A case study in winter shows the typical synoptic system and distinctive mesoscale phenomena. The temporal and regional features of temperature variations, which are accompanied by the pass of a cold front, are focused on. For example, in Nemuro Plain, the inland of southeastern Hokkaido, temperature rises suddenly and temporarily right after the cold front passage, chiefly because the inversion layers are destroyed by downslope wind on the lee side. This exceptional weather system is worth noting not only in meteorology but also in synoptic climatology.

Key words: weather system, cold front, North Japan, synoptic climatology, destruction of inversion layer

1. Introduction

Accumulating knowledge of frontal weather systems is really significant in terms of synoptic climatology (*e.g.*, Jacobs, 1947; Maejima, 1967; Mikami, 1978), theories of climatic division (*e.g.*, Maejima, 1969; Yazawa, 1990) and mesoscale meteorology (*e.g.*, Fujita, 1955; Atkinson, 1981).

In order to understand a weather system of passing cold fronts over North Japan (Fig. 1), several meteorological elements which are based mainly on 'AMeDAS' and data on surface and upper air at the meteorological observatories, are analyzed.

'A weather system' is defined as the synthetic concept of synoptic situation, cloud system, precipitation, wind system, temperature and so on, including their temporal time and spatial distribution, creating process and mutual relationship.

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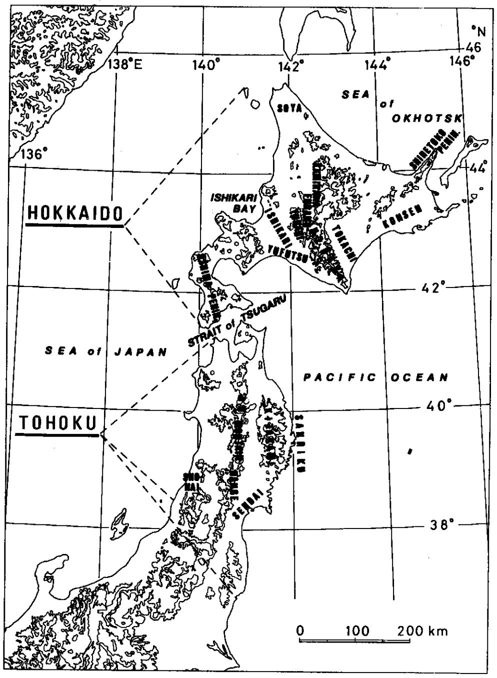

Fig. 1 Geographical map of study area

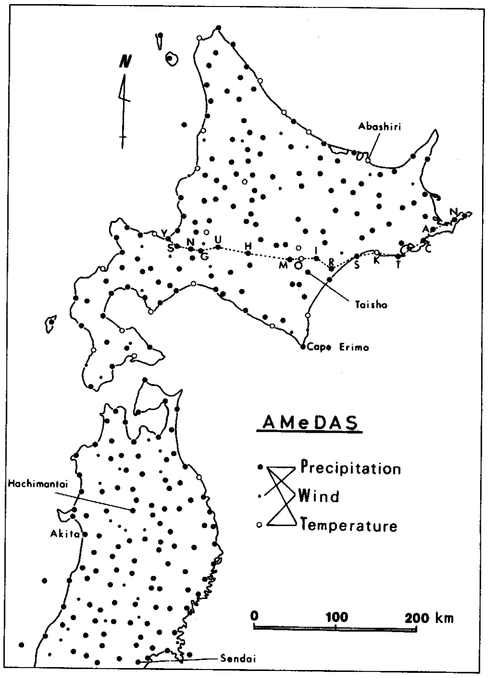

Fig. 2 Distribution of 'Automated Meteorological Data Acquisition System (AMeDAS)'.
Y: Yamaguchi, S: Sapporo, N: Nishinopporo, G: Naganuma, U: Yubari, H: Hidaka, M: Memuro, O: Obihiro, I: Ikeda, R: Urahoro, S: Shiranuka, K: Kushiro, T: Ota, C: Sakakimachi, A: Attoko, N: Nemuro.

2. Data and Methods

Synoptic situation and cloud system are examined by using weather charts and satellite data (GMS-1, VIS). Features of precipitation, wind and temperature are analyzed by means of distribution maps and section diagrams (isopleths) based on 'AMeDAS' (Fig. 2). Conditions of lower atmosphere are investigated on the basis of 'Aerological Data of Japan'.

As a typical example of a case study, a passing cold front over North Japan on 26 to 27 February 1980 is chosen, because the system has clear wind shear and geographical weather contrasts. Climatological characteristics are also reviewed in comparison with other cases.

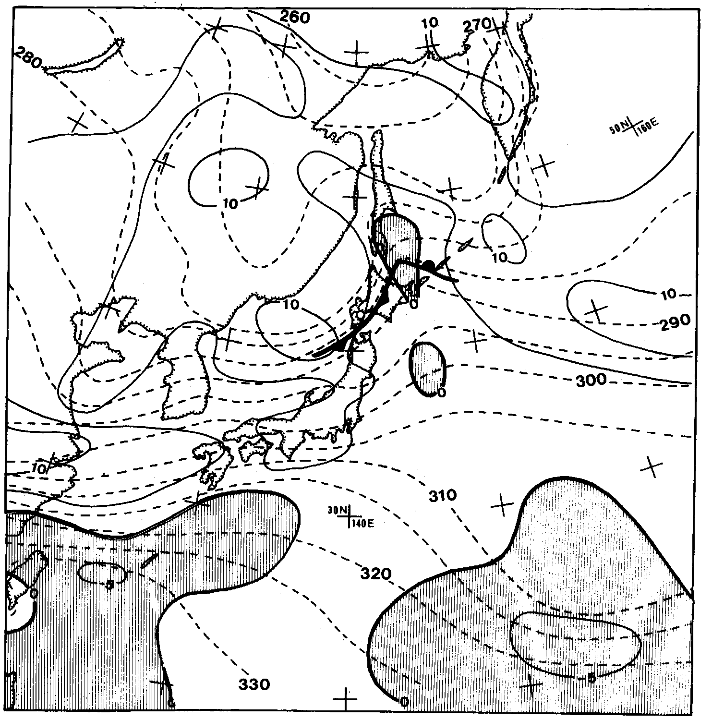

Fig. 3 Synoptic weather chart of low-level atomosphere at 21JST on 26 February 1980
Fronts and equivalent potential temperature on 850 mb level and stability index by means of the difference in equivalent potential temperature between 700 mb and 850 mb levels are indicated. The areas with stripes show convective instability.

3. A Case Study

Synoptic situation

At 09JST, on 26 February 1980, an extratropical cyclone passed over Sakhalin and then a cold front extending southwestward from the cyclonic center passed through Hokkaido and the Tohoku district, North Japan.

Equivalent potential temperature at 850 mb level (broken lines) and stability index, *i.e.*, its temperature differences from 700 mb to 850 mb (solid lines) at 21JST on 26 February 1980 are shown in Fig. 3. Around the cyclone's center and in a part of the warm sector, unstable air masses exist. Moreover, the baroclinic instability is shown markedly. The developmental condition of vertical clouds was satisfactory.

The cold frontal cloud band was 200 to 300 km wide over the Sea of Japan in its vertical direction and its southern edge was located at 37° 51'N. Its brightness was a little high around 40° N, but as a whole nearly homogeneous. After the front was passing, synoptic situation resulted in migratory anticyclonic pattern which had a moderate pressure gradient.

Wind system before and after the frontal passage

Streamline charts of wind systems are illustrated in Fig. 4. Before the pass of a front (Fig. 4-a), southwesterly wind blew at a speed of about 10 m/sec along the coasts of the Seas of Japan and Okhotsk, including the Soya Hills. Strong wind was observed around Cape Erimo, Shonai Plain, Hachimantai and so on. It is characteristic of strong windy area to be recognized over the area from Yufutsu Plain through to Ishikari Plain and the middle reaches of a Ishikari River and in the Furano and Kamikawa Basins.

On the contrary, calm areas were found to the east of the Hidaka mountain range. In some parts of Tokachi Plain, weak northwesterly wind (1 to 3 m/sec) was observed despite the fact that it belonged to the cyclone's warm sector. This kind of northwesterly wind is often recorded in the Tokai District, southern central Japan, too.

The strong windy area is recognized along the coast of the Sea of Japan in Hokkaido after the pass of a front (Fig. 4-b). Northwesterly wind which was converged and enhanced in Ishikari Bay divided into two streams; one flowed southeastward from Ishikari Plain, the other, eastward over the mountainous district of Yubari and the Hidaka mountain range into Tokachi Plain. It is remarkable in the Tohoku District that strong northerly wind blew in the lower reaches of Kitakami River, Sendai Plain.

These typical wind systems agree with the results by Kawamura (1963, 1977). The wind system in the warm sector is similar to the type D flow pattern accompanying

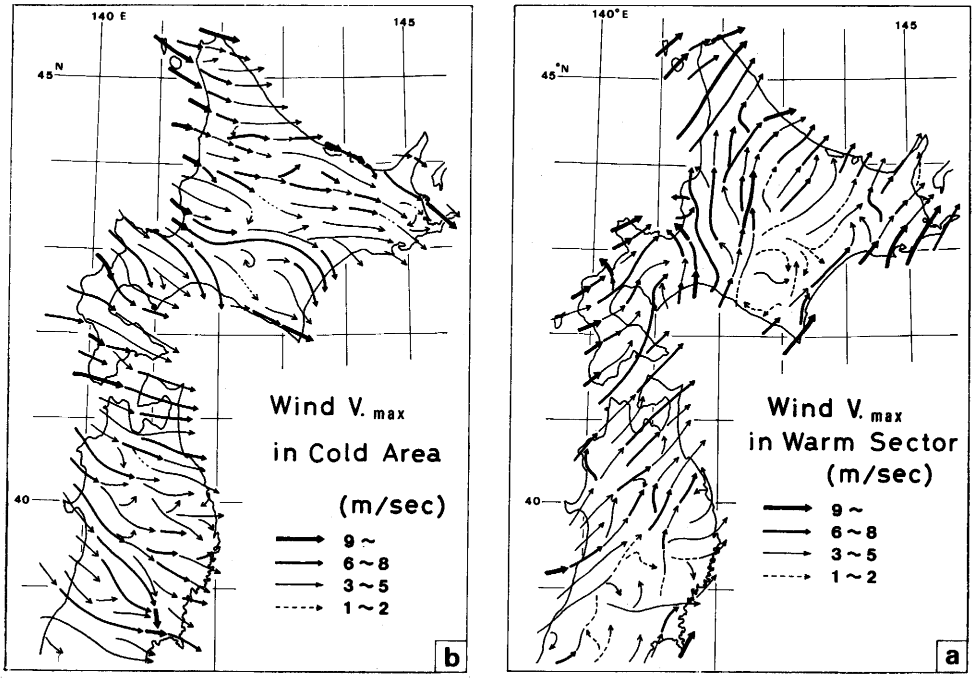

Fig. 4 Maximum wind velocity before (a) and after (b) the pass of the cold front on 26 February 1980

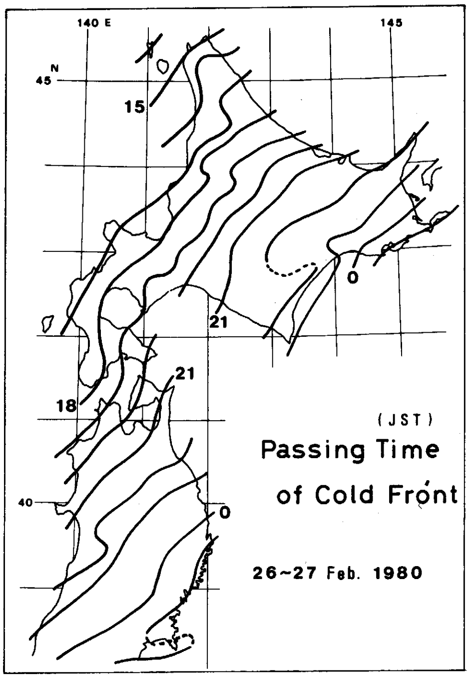

Fig. 5 Passing time of the cold front from 26 to 27 February 1980, on the basis of the changes of wind direction

240-270° of surface gradient wind direction; while in the cold area, the type B with 310-360°.

Passing speed of the front

The cold front, which moved eastward at a speed of about 30 km/h, slowed down when it reached the Japanese Archipelago due to orographic friction (Fig. 5); besides, the moving speed reduced by half because of geomorphic factors of the Hidaka mountain range and the Ishikari mountainous region.

On the other hand, the front accelerated the speed at a dash over Tokachi Plain and around Abashiri. In Konsen Plain and its surroundings when southwesterly wind was excellent, it slowed down speed again (Figs. 5 and 8).

Relationship between precipitation and landforms

Over the southwest slope of the Hidaka Mountains, which were located on the windward side of a warm air mass, much precipitation began to be brought three or four hours ahead of the arrival of the front (Figs. 6 and 8). That is why northeastward humid wind passed through the Strait of Tsugaru being to the southwest of Hidaka mountain range without obstacles. That is also why the humid air mass set up ascending currents over the windward slope of the mountains.

In addition, on the east side of the Ou mountain ridge, running from north to south along the center of the Tohoku district, the front Dropped a great deal of precipitation (Fig. 6).

Precipitation divides shifted to the lee side of the ridge lines (Fig. 5). The areas

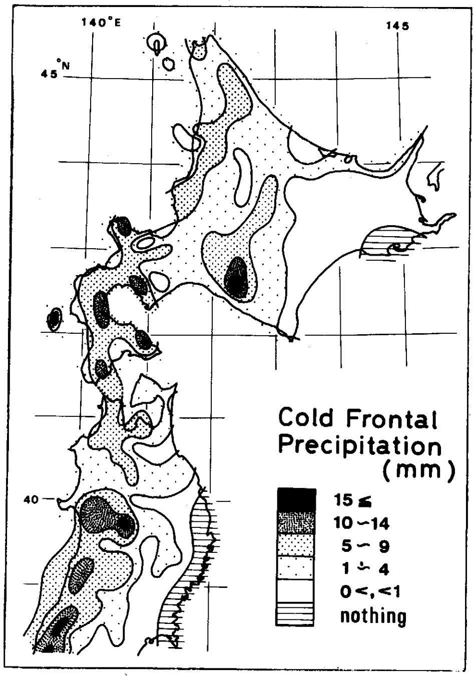

Fig. 6 Total precipitation incidental to the passing cold front

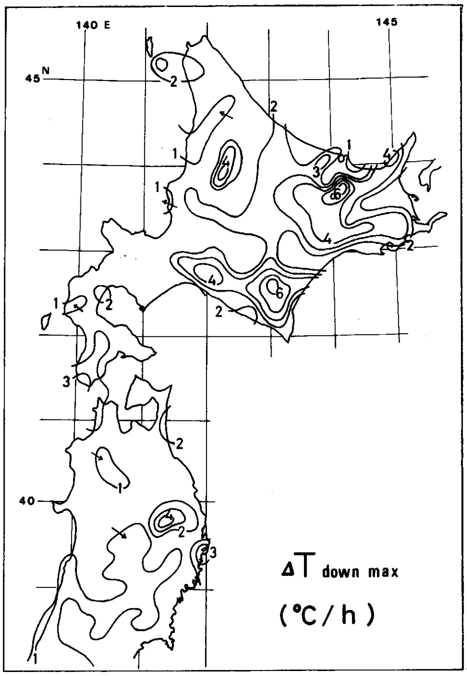

Fig. 7 Maximum dropping temperature after the pass of the cold front

with no or a few precipitation (<1 mm) are shown in almost all points of the eastern part of Hokkaido and the Sanriku coastal region on account of the effect of mountain shadow. This contrastive weather pattern corresponds to the analyzed results of passing cold fronts over Japan (Yamakawa, 1980; Yamakawa, 1981; Yamakawa, 1984).

Relationship between temperature and wind systems

Wind shear is the best indicator of passing cold fronts, in spite of the above-mentioned regionality of wind systems. Temperature is also important to analyze fronts, but there are regional differences in temperature variation patterns. After the pass of a cold front, temperature dropped generally, but distributions of cooling patterns differ geographically (Fig. 7).

Before the front passed, temperature had already declined in some stations; for example, Yamaguchi to Naganuma, Shiranuka, Nemuro and so forth, especially Memuro located in the west of the Tokachi Plain (Figs. 1 and 8), and the Konsen Plateau (Fig. 9-a), chiefly because of radiational cooling.

It is noteworthy that temperature rose against the ordinary phenomena when the cold front passed in some areas of the eastern Hokkaido. Cold air lakes, which had been created by radiational cooling, were drastically destroyed by strong current descending over the mountains, so that temperature was abruptly elevated. Especially, in the central part of Tokachi Plain partly comprising a basin, temperature was

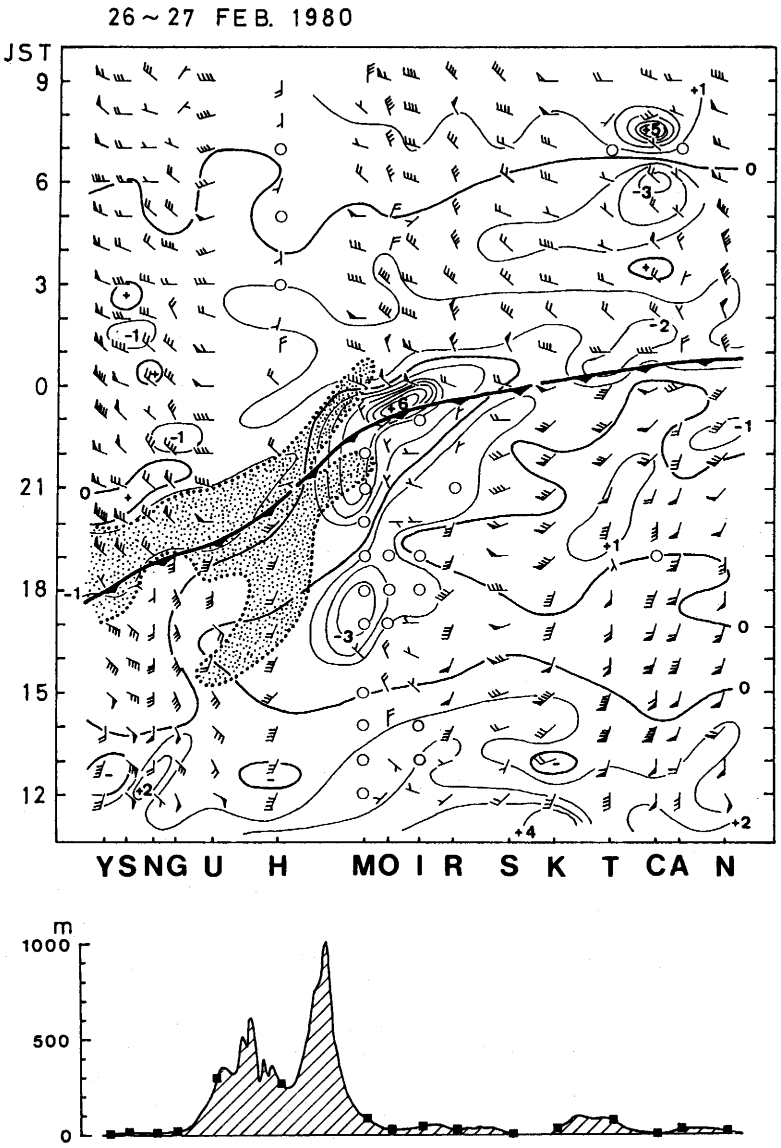

Fig. 8 Time and space section diagram of weather systems before and after the pass of the cold front on 26 to 27 February 1980 (See Fig. 2 for the position and names of the stations)

raised by 6.7° C (Fig. 8) at Obihiro, and by 8.5° C at Taisho per hour from 23JST 26 February to 00JST 27 February (Fig. 9-a), respectively.

Rising temperature after the passage of the front was also found on the southeast side of the Shiretoko Peninsula at the same time (Fig. 9-a).

The exceptional rise of temperature resulted chiefly from the destruction of inversion layers of the cold air lakes, and partly from fōhn accompanying downslope wind on the lee side over the mountains. Such cold frontal warming corresponds to what is called 'north fōhn' (Suzuki and Yabuki, 1957; Yoshino, 1975). The 'anticyclonic fōhn,' namely the downward current from the upper layer which fills up the basin where the cold air has blown away (Walter, 1938), resembles the phenomena pointed out here, in that cold air replaces warm air but under another synoptic process.

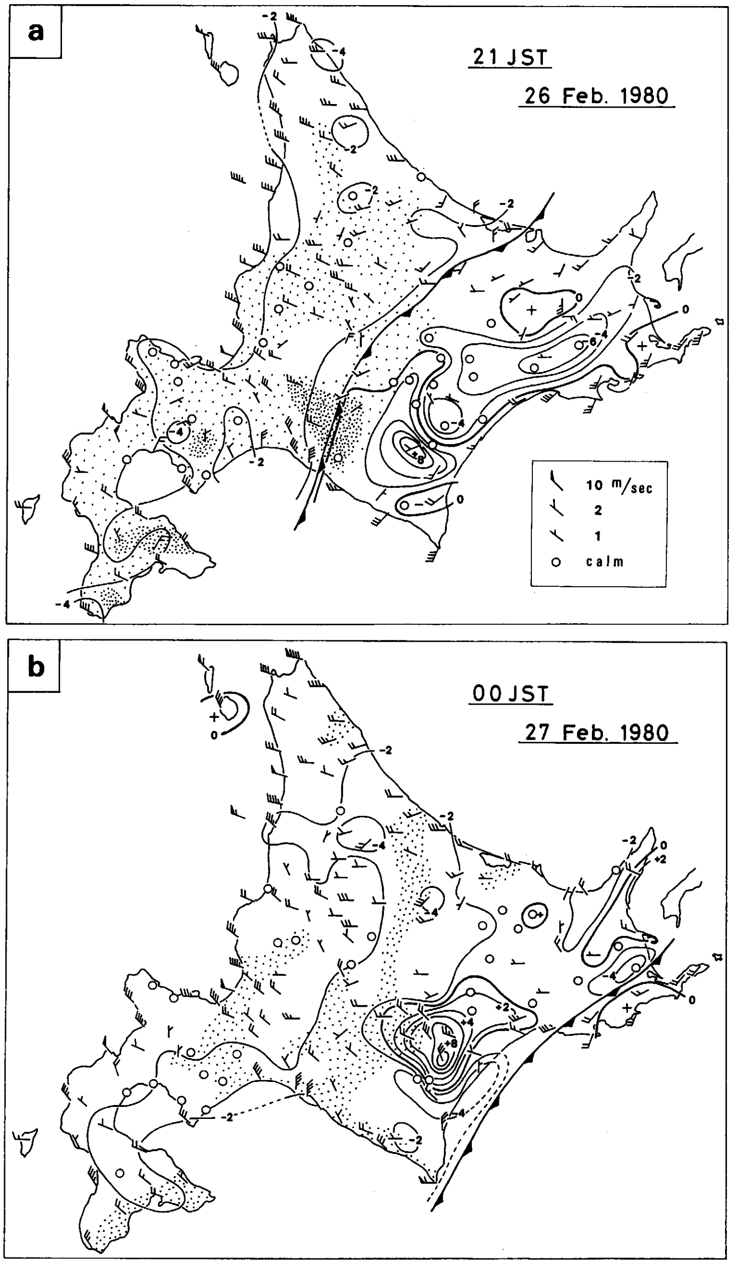

Fig. 9 Mesoscale weather systems at 21JST on 26 February (a) and at 00JST on 27 February (b) 1980

The zone which is 100 to 200 km apart from the cold front in a northwesterly direction was cooled more by a fresh cold air mass (Fig. 9-a and b).

Upper air structure around the front

Using aerological data on Sapporo and Nemuro, a section of space and height is illustrated (Fig. 10-a), which includes the spatial values converted from data with 6-hour and 12-hour time lags. A section diagram is also drawn by means of data on Akita and Sendai likewise (Fig. 10-b).

Wind speed (broken lines) and cloud area presumed by relative humidity are shown in the diagrams. The cold frontal surface (double lines) was accompanied by active cumuli and low-level jet stream at a speed of about 25 m/sec, which was enhanced by momentum transport of the upper-level jet stream above the frontal surface. The upper jet over Tohoku District (Fig. 10-b) was stronger than that over Hokkaido (Fig. 10-a), but the cloud systems formed similarly.

A few clouds and weak wind inside the warm sector contributed to radiational cooling. In conclusion, the low-level jet destroyed inversion layers of the cold air lakes.

Climatological study on the phenomena being presented in this paper is very

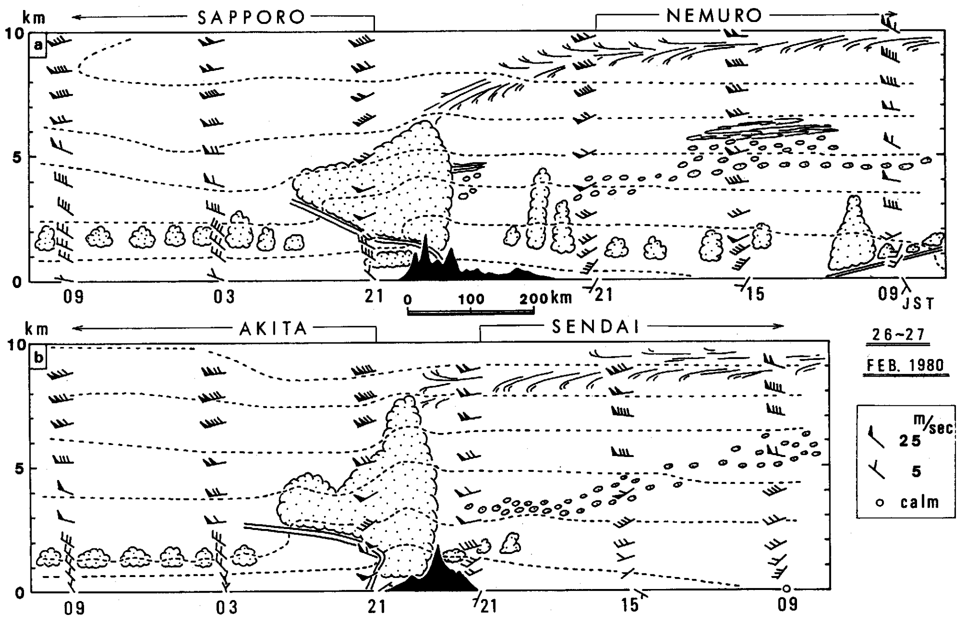

Fig. 10 Horizontal and vertical diagrams along a W-E section of the central Hokkaido (a) and a NW-SE section of the central Tohoku (b) around the cold frontal surface (doublelines).
Wind velocity (arrows), temperature (bloken lines) and cloud systems are shown, based on aerological data at Sapporo and Nemuro (a) and Akita and Sendai (b), including time-space conversion.

important. Therefore, it will be pursued and reported in another paper comparing similar cases at home and abroad.

4. Concluding Remarks

The results obtained in this study are summarized as follows:

1) The southwesterly wind in the warm sector is strong in the coasts of the Seas of Japan and Okhotsk, around Cape Erimo, the Yufutsu Plain, Ishikari Plain and Konsen Plain. The strong northwesterly wind in the cold area is also found similarly in the same regions, but in the Tokachi Plain the former is considerably weaker than the latter.

2) The passing cold front over North Japan brings about contrastive weather. Much precipitation is observed on the west side of the inland mountain ranges, while there is no or a little precipitation on the east side.

3) In general, after the cold fronts pass, temperature drops. Exceptionally at some winter nights, however, temperature rises temporarily after the pass in the restricted regions.

4) Temperature is raised extraordinarily not only by föhn effects but also the destruction of inversion layers within the cold air lakes due to northwesterly wind on the lee side. The typical example is shown markedly in Tokachi Plain, with a topographically basinal tendency.

5) A cold air lake is often formed as a result of radiational cooling on a fine, not windy day over the region facing the Pacific Ocean. There exists an obvious relationship between low-level jet around the cold front and the upper jet stream above the frontal surface.

Acknowledgment

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