Classification of the Yamase (Cold Northeasterly Wind around Northeastern Japan) Based upon its Air-Mass Vertical Structures

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Abstract

The Yamase wind—a cold northeasterly wind which produces cool weather in summer over northeastern Japan—was classified by using upper-air meteorological data. A cluster analysis was performed of the vertical structures of the Yamase air masses, which were divided into seven clusters. The mean features of the Yamase air mass in each cluster are investigated. The surface low temperature area is in proportion to the Yamase air mass height but the air mass height does not always correspond to the height of the easterly wind. In the case of the Yamase air mass and easterly wind being both high (over about 800 hPa), the surface easterly wind blows over northeastern Japan and an extremely low temperature area spreads over the Pacific side (Clusters 2 and 6). In the case of the easterly wind being high (over about 800 hPa) but the Yamase air mass being low (below about 800 hPa), the surface easterly wind blows over northeastern Japan but the surface temperature is not extremely low, and the cold air is effectively blocked by the mountain range (Clusters 3 and 5). In the case of the easterly wind and Yamase air mass heights being both low, the surface easterly wind and low temperature area are restricted to the Pacific side (Clusters 1, 4 and 7). The Yamase wind appearances in each cluster show a seasonal dependence; the Yamase wind included in Clusters 6 and 7 blows only in June, that in Clusters 2 and 4 appears mainly in the Baiu season, in Clusters 1 and 3 it blows from late Baiu to summer, and in Cluster 5 blows in the summer season. Also the surface pressure pattern, front distribution, and the mean 500 hPa geopotential height field have the unique characteristics in each cluster. The Yamase-wind appearances in each year indicate that the severe cool summer years (1980, 1988, 1993) are induced by the Yamase winds classified in Clusters 2, 3, and 4; however, the Yamase wind in Cluster 2 having a thick and cold air mass plays an especially important role in causing a cool summer.

1. Introduction

A cold northeasterly wind, called the “Yamase wind”, sometimes blows over northeastern Japan from the Baiu season (rainy season between spring and summer) to summer. Since the Yamase wind induces cool weather, the crops suffer damage when it blows continuously. The following characteristics of the Yamase wind have been clarified:

When the typical Yamase wind blows, the temperature is lower on the eastern (Pacific) side of the central mountain range and higher on the western (Japan Sea) side through the damming up of the cold air mass (Asai, 1950; Kudoh, 1981). Since clouds are blocked by the mountains, there are few clouds on the western side of the mountain range (Bokura, 1975). The surface easterly

wind has a diurnal change with the maximum wind speed in the daytime (Riki-ishi and Sasaki, 1990). The Yamase wind is produced by a characteristic pressure pattern, such as an anticyclone located over and/or around the Sea of Okhotsk, and a cyclone and front lying along the southern coast of Japan. The vertical structure of the typical Yamase air mass is characterized by a thin mixed layer and an upper stable layer (Kudoh, 1984; Ninomiya and Mizuno, 1985b; Urano, 1990; Kodama and Yamamoto, 1990). Since the height of the Yamase air mass is less than 2000 m, it is easily blocked by the mountains of 1000–2000 m above sea level. According to Ninomiya and Mizuno (1985a), the Yamase wind induces large summer temperature variations, greatly influencing the summer climate in northeastern Japan. Just for reference, the above-mentioned results are collected in Kawamura (1995).

As mentioned above, the features of the typical Yamase wind have been clarified, but its general characteristics, such as climatological and statistical aspects of diverse Yamase winds, are still unclear. The Yamase wind blows even in the normal temperature summer; however, the investigation of such a usual Yamase wind is insufficient. To investigate the general characteristics of the Yamase, we think that its classification is one useful method. The averaged characteristics of the Yamase wind and the sea wind in northeast Japan have been shown by Kanno (1993), but the classification of the Yamase wind has not yet been presented.

We performed a cluster analysis of the vertical structures of Yamase air masses by using upper-air meteorological data to classify the Yamase wind. A principal component analysis is usually applied to meteorological analyses. This is useful to summarize data and to find the factor which controls the variables of samples. On the other hand, the principle of a cluster analysis is that the distance, *i.e.*, similarity is calculated between observations, which are combined in the order of short distance and can be classified objectively. Therefore, we selected a cluster analysis to classify the Yamase wind. The principle of a cluster analysis and its application to meteorological data are to be found in Tagami (1982).

In this study, the Yamase wind is classified not by using the atmospheric circulation and surface pressure pattern but using the stratification of the Yamase air mass. According to Kanno (1995), low-temperature areas during the Yamase wind may be largely connected with the Yamase air-mass height. We believe that the factor which causes various low-temperature distributions can be analyzed by the classification of the Yamase wind based on the stratification of air mass.

2. Data and analysis techniques

Figure 1 shows the geographical map of northeastern Japan. For the cluster analysis, we used the aerological observation data (0000 UTC) at the Misawa meteorological station. Data are also available from the Sendai station along the Pacific coast in northeastern Japan; however, the data from Sendai indicate a more modified air mass than Misawa due to its southerly location. Therefore we used the data at Misawa for the cluster analysis.

To investigate the characteristics of the Yamase air mass, we used the vertical profiles of temperature, potential temperature (θ), equivalent potential temperature (θ_e), mixing ratio and wind, and the surface distributions of wind, daily mean temperature deviation and pressure, and 500 hPa geopotential height. These were all averaged in each cluster.

θ_e is the pseudo equivalent potential temperature, the surface-wind vector is averaged every hour from

Fig. 1. Geographical map of northeastern Japan.

Contours indicate 500 m, 1000 m, and 1500 m above sea level. Misawa, Sendai, and Akita are aerological observation stations. The hourly data from the Hachinohe weather station were used to distinguish the Yamase-wind events.

1000 JST to 1500 JST, and the daily-mean temperature deviation is the difference from the 15-year mean from 1979 to 1993.

For the analysis of surface meteorological features, we used the data from weather offices and the Automated Meteorological Data Acquisition System (AMeDAS) stations—the surface meteorological observation stations densely spread over Japan—from the Japan Meteorological Agency (JMA). All analyses were performed with data for the period 1979–1993 from June to August.

Mean surface pressure and 500 hPa geopotential height are computed by averaging the most recent 10 cases in each cluster for 5 degrees latitude-longitude grid data which were taken from surface weather maps published by the JMA. The surface fronts are also plotted on the mean field. To investigate the variability of the pressure patterns, the standard deviation of surface pressure is shown in the figures.

2.1 Description of Yamase-wind days

The Yamase-wind days were distinguished from other weather condition days by using the hourly data at the Hachinohe meteorological observation station. The criteria proposed by Kanno(1993) were used:

- (i) Over three-fourths of the wind directions during one day are north and/or easterly (N-SSE).

- (ii) Daily-mean temperature deviation from the normal is negative or zero.

The days satisfying the above-mentioned conditions were selected as the Yamase-wind days. As a result, we extracted 397 cases.

These criteria are not as strict as the previous method proposed by Kon (1984), so more Yamase-wind days are discriminated in this work. The previous criterion would be used to select the extremely cold Yamase winds which cause cool-weather damage to the crops. On the other hand, our aim is to elucidate the general features of the Yamase wind, and thus we need to pick up the weak Yamase-wind cases.

2.2 Procedure for cluster analysis

The Ward's minimum variance cluster analysis was performed using the aerological observation data for the Yamase-wind days. Since the raw data were not suitable for statistical analysis owing to the unsettled observation height of the significant levels from day to day, the data were linearly interpolated to the 51 levels at 10 hPa intervals from the surface to 500 hPa. The standardized data of potential temperature (θ), θ 's lapse rate, and the u-component of wind were used in the analysis. They indicate well the air mass stratification and wind profiles. Other meteorological elements were also tried for the cluster analysis; however, the above three elements were the best for classifying the Yamase air mass. The total number of variables is 152: 51 levels of θ and the u-component plus 50 levels of the lapse rates. After clustering the Yamase-wind days, the upper and surface meteorological data were averaged in each cluster for investigating the features of the Yamase air mass. Although the averaged data sometimes hide the individual character, the general features become more clear.

Figure 2 shows the dendrogram of the cluster analysis. The number of clusters was verified by using the averaged meteorological data. In consequence, Cluster 4 is made by combining two similar clusters and should not be separated further. Also, Clusters 6 and 7 are never combined because the characteristics are different. As a result, 397 cases of the Yamase-wind days (Yamase air masses) were divided into seven clusters. Cluster 4 is the biggest having 98 cases, and Cluster 7 is the smallest having 14 cases.

3. Characteristics of the Yamase air mass in each cluster

To investigate the Yamase air mass, we focus on the height of the stable layer. According to the case study by Kanno (1991), stable stratification is formed in the Polar maritime air mass (Pm air mass) in the Sea of Okhotsk and the Bering Sea,

Fig. 2. Dendrogram of cluster analysis.

Bold numbers are the cluster numbers. The numbers in parentheses indicate the total sample numbers. Semipartial R-squared is the decreasing rate of the variance ratio of contribution by combining two clusters.

which is considered as the origin of the Yamase air mass. Also, Urano *et al.* (1990) showed that the stable layer is formed upstream of the easterly wind (Yamase wind) and the mixed layer gradually increases its thickness with southwestward movement. They suggested that the Pm air mass originally has a stable stratification and the mixed layer is then formed by the heating from the sea surface with its southward movement; then the Yamase air mass having a lower mixed layer and upper stable layer is created in the northeasterly wind. Therefore, in the case of the easterly wind prevailing at all levels, we may consider the height of the stable layer as the upper part of the Yamase air mass.

We defined the stable layer by using a temperature lapse rate less than $0.4^{\circ}\text{C}/10$ hPa (about $0.4^{\circ}\text{C}/100$ m) and the other meteorological element profiles. For this lapse rate, the reader is referred to Kato (1985), who considered layers whose lapse rates were less than $0.4^{\circ}\text{C}/100$ m as the stable layers by analysing the lower atmosphere over the Sea of Okhotsk.

3.1 Cluster 1

Figure 3 shows the vertical profiles of temperature, θ , θ_e , wind, mixing ratio, and the lapse rates of temperature and θ_e . The vertical profile of θ indicates a thin mixed layer under 980 hPa. The temperature stable layer is found between 980 hPa and 800 hPa ($-\partial T/\partial p$ is less than 0.4°C), but the θ_e lapse rate indicates a conditionally unstable layer existing above 910 hPa ($\partial\theta_e/\partial p$ is about 0 K), and then a stable stratification is formed between 980 hPa and 910 hPa. The vertical profile of the

Fig. 3. Vertical profiles of mean temperature, potential temperature (θ), equivalent potential temperature (θ_e), wind, mixing ratio (W), and the lapse rates of temperature ($-\partial T/\partial p$) and θ_e ($\partial \theta_e/\partial p$) at the Misawa aerological observation station for Cluster 1 (0000 UTC).

Bars indicate the margins of standard deviation. Arrows indicate the upper limit of the Yamase air mass.

mixing ratio shows a constant value below the stable layer. The wind direction is easterly below 940 hPa and westerly above it. This easterly wind layer can be defined as the Yamase air mass having uniform moisture conditions.

Figure 4 shows the surface-wind distribution and daily-mean temperature deviation. An easterly wind is restricted to the northern and the coastal areas of northeastern Japan, and a westerly wind prevails west of the central mountain range. The low-temperature area (temperature deviation under -1°C) is restricted around the Shimokita Peninsula, and this may be induced by the invasion of the relatively thin Yamase air mass.

3.2 Cluster 2

An easterly wind blows below 600 hPa and the wind speed is over 7 ms^{-1} between 950 hPa and 850 hPa (Fig. 5). The temperature lapse rate indicates that a mixed layer is formed below 980 hPa and a stable layer between 980 hPa and 770 hPa. The lapse rate of θ_e and the vertical absolute humidity gradient are nearly uniform up to 500 hPa. The stable layer formed in the easterly wind may correspond to the upper part of the air mass, and then the upper limit of the Yamase air mass in Cluster 2 is defined as 770 hPa.

On the surface, an easterly wind prevails over the whole area (Fig. 6). Two streams of strong easterly winds run from the Pacific to the Japan Sea going around the Kitakami Mountains. Ex-

Fig. 4. Surface wind distribution and daily-mean temperature deviation ($^\circ\text{C}$) for Cluster 1.

Surface wind vector is averaged from 1000 to 1500 hours every hour and the daily-mean temperature deviation is the difference from the 15-years mean which is averaged from 1979 to 1993. Thin solid lines indicate the contour lines of 500 m, 1000 m and 1500 m above sea level; broken lines are 200 m.

Fig. 5. As in Fig. 3, except for Cluster 2.

Fig. 6. As in Fig. 4, except for Cluster 2.

tremely low-temperature areas with a daily mean temperature deviation under -3°C are located at the northeast and the south on the Pacific side. On the other hand, because of the damming up and/or modification of the Yamase air mass by the central mountain range, temperatures on the Japan Sea side are higher than on the Pacific side. However, it is noted that the relatively low temperature deviation ($\sim -2^{\circ}\text{C}$) is found even on the Japan Sea side. It is suggested that the thick Yamase air mass induces the strong surface easterly wind and the extremely

low temperature over the large area including the Japan Sea side in this cluster.

3.3 Cluster 3

The wind direction turns from east to west around 800 hPa (Fig. 7). The vertical gradients of temperature and θ indicate a mixed layer below 960 hPa. A temperature stable layer is located between 960 hPa and 750 hPa, but the lapse rate of θ_e indicates that an unstable stratification exists above 830 hPa by conditional instability, and a stable layer is formed between 960 hPa and 830 hPa. Thus the Yamase air mass height is defined as 830 hPa and shows a small lapse rate in the mixing ratio.

The surface easterly wind runs from the Pacific side to the Japan Sea side, but the wind speed is less than that for Cluster 2 (Fig. 8). The low-temperature area is located on the eastern side of northeastern Japan and the isobar of -2°C runs along the central mountain range. It seems that the cold air is effectively blocked, unlike Cluster 2, by the central mountain range because the height of the Yamase air mass is lower.

3.4 Cluster 4

An easterly wind blows below 880 hPa and its height is lower than Clusters 2 and 3 (Fig. 9). A mixed layer is formed below 980 hPa. A temperature stable layer is formed between 980 hPa and 820 hPa, but the lapse rate of θ_e indicates an unstable stratification existing above 870 hPa. The wind direction changes from east to west around the upper limit of the stable layer. The Yamase air-mass height is defined as the easterly wind height of 880 hPa and indicates a small lapse rate in the mixing ratio.

Fig. 7. As in Fig. 3, except for Cluster 3.

Fig. 8. As in Fig. 4, except for Cluster 3.

A surface easterly wind does not blow on the Japan Sea side (Fig. 10). Low-temperature areas (daily-mean temperature deviations below -2°C) 30–60 km in width are found along the Pacific coast. The lowest-temperature deviation below -3°C is seen locally around Hachinohe. This temperature distribution indicates that the Yamase air mass in this cluster is largely affected by the Kitakami Mountains rather than as in the cases of Clusters 2 and 3, and this may be caused by the lower air-mass height.

3.5 Cluster 5

An easterly wind prevails at all levels and the maximum wind speed is found around 900 hPa (Fig. 11). A mixed layer is formed below 980 hPa. The lapse rates of θ_e and temperature indicate a stable layer between 970 hPa and 930 hPa, whereas a stable layer in this cluster is relatively unclear. In considering the height of the stable layer and the vertical profile of the mixing ratio, the Yamase air-mass height is defined as 930 hPa.

The surface easterly wind runs from the Pacific to the Japan Sea side as in Cluster 2 (Fig. 12), but the temperature is not extremely low—the daily mean temperature deviation west of the central mountain range is above 0°C . Daily-mean temperature deviations below -1°C are seen along the Pacific coastal area. In this cluster, although the strong surface easterly wind blows, the Yamase air mass is thin and may be easily modified over the land and blocked by mountains so that the low temperature is restricted to the Pacific coastal area.

3.6 Cluster 6

The wind direction turns 180 degrees at around 760 hPa and the easterly wind speed is larger near the surface than in the upper level (Fig. 13). The temperature is the lowest of all the clusters. The lapse rate of temperature suggests that a mixed layer is formed below 960 hPa and a stable layer is present between 930 hPa and 810 hPa; however, the lapse rate of θ_e is small (under 0.4 K) below 900 hPa and shows that a conditionally unstable stratification is formed in this layer. As a result, a stable stratification is formed between 900 hPa and 810 hPa. The air under this stable layer is defined as the Yamase

Fig. 9. As in Fig. 3, except for Cluster 4.

Fig. 10. As in Fig. 4, except for Cluster 4.

air mass having a small lapse rate in the mixing ratio.

The surface easterly wind is distinct in the north of northeastern Japan, but relatively weak in the south (Fig. 14). The extremely low-temperature areas (daily mean temperature deviations below -4°C) are widely spread on the eastern side of the central mountain range and this distribution pattern resembles Cluster 2. The Yamase wind in this cluster has a cold and thick air mass and the cold air can easily invade the inland area.

3.7 Cluster 7

An easterly wind layer is restricted to near the surface and the wind speed is the lowest of all the clusters (Fig. 15). The temperature lapse rate indicates that this thin easterly wind layer below 980 hPa has an unstable stratification. The surface wind direction is from the sea to inland (Fig. 16). The low-temperature area—daily mean temperature deviation below -1°C —is found in the northern part of the study area, and it may be induced by the shallow cold air (like a thin easterly wind layer shown in Fig. 15) invasion. Such a shallow cold air mass was observed at the Shimokita Peninsula by Kanno *et al.* (1991); it was 200 m in height and was invaded by the sea breeze. It suggests that the shallow cold air mass is sometimes found on the sea around northeastern Japan and brings low temperatures along the seashore in the warm season, but the temperature deviation is not large.

The mean sunshine durations in each cluster show a common distribution pattern during the Yamase-wind events; that is, the sunshine duration is short on the Pacific side (1–2 hours in a day) and relatively long time on the Japan Sea side (4–6 hours). However, in Cluster 7, the sunshine duration is not short: 2–5 hours on the Pacific side and 5–7 hours on the Japan Sea side. This suggests that the shallow cold air mass in Cluster 7 does not accompany much cloud and/or fog.

3.8 Relations between low temperature area and Yamase air mass height

In most of the previous case studies, a stable layer was formed around the turning point of wind direction from the lower easterlies to the upper westerlies,

Fig. 11. As in Fig. 3, except for Cluster 5.

Fig. 12. As in Fig. 4, except for Cluster 5.

where the air in the lower easterly wind was defined as the Yamase air mass. For example, Ninomiya and Mizuno (1985b) defined the Yamase air mass as the easterly and/or northeasterly wind, and Watanabe (1990) specified the upper limit of the air mass as the height of the stable layer and the thickness of the easterly wind corresponding to it. Also, Kudoh (1984) defined the Yamase air mass (the so-called modified Okhotsk air mass) as the easterly wind.

However, like the case of Cluster 5, the air mass height does not always correspond to the height of the easterly wind; the thickness of the easterly wind is up to 500 hPa, but the Yamase air-mass height is only 930 hPa. Therefore the height of the Yamase wind has to be synthetically determined by using not only the thickness of the easterly wind, but also some meteorological elements.

Table 1 shows the features of the Yamase wind in each cluster. A conclusion is that the low-temperature area is in proportion to the Yamase air mass height but the air mass height does not always correspond to the height of the easterly wind. These features of the low temperature area, air mass and easterly wind height are summarized as follows;

In the case of the Yamase air mass and easterly wind having the height above about 800 hPa, the surface easterly wind blows over northeastern Japan and the extremely low temperature area spreads over the Pacific side. Even on the Japan Sea side, the temperature is low. Clusters 2 and 6 are included in this case.

If the easterly wind has the height above about 800 hPa but the Yamase air mass is lower than 800 hPa, the surface easterly wind blows over northeastern Japan but the surface temperature is not extremely low, and the cold air is effectively blocked by the mountain range. Clusters 3 and 5 are included in this case.

In the case of the easterly wind and Yamase air mass heights being both low, the surface easterly wind and low temperature area are restricted to the Pacific side. Clusters 1, 4 and 7 are included.

Fig. 13. As in Fig. 3, except for Cluster 6.

Fig. 14. As in Fig. 4, except for Cluster 6.

4. Mean surface pressure and 500 hPa geopotential height in each cluster

The mean surface pressure and front distribution in Cluster 1 are shown in Fig. 17, and the mean 500 hPa geopotential height field is shown in Fig. 18. The Okhotsk high is located to the east of Hokkaido and the north Pacific high is formed to the east of 160°E (Fig. 17). There is a frontal zone around 30–40°N, but the positions of the fronts are not stable. The standard deviation of pressure is generally small except over the northern part of the Pacific Ocean

and around Lake Baikal. The large standard deviation area in north Pacific may be induced by the passage of fronts and cyclones. The isobars around Japan run north and south, and some surface fronts pass over Japan.

The 500 hPa geopotential height distribution indicates two troughs along 120°E and 170°E and a ridge from the Pacific Ocean to the west of the Sea of Okhotsk (Fig. 18). There are two axes of westerly wind—one streams from Siberia to the north Pacific through the Sea of Okhotsk and the other streams from Mongolia to the north Pacific. The southern axis passes over Japan and this is accompanied by the surface fronts. The surface Okhotsk high is formed on the eastern part of the 500 hPa ridge. According to Okawa (1973), this type of surface Okhotsk high is a cold anticyclone and it is continuously formed by the effect of the upper convergence area.

Figure 19 shows the seasonal frequency of Yamase-wind days in each cluster. In Cluster 1, they appear during all of the period from June to August, but the frequency after July is larger. As a result, the Yamase wind in this cluster blows when the Okhotsk high is located to the northeast of Japan and a cyclone and/or a front pass over Japan from the Baiu to summer.

Figures 20 and 21 show the mean surface pressure and 500 hPa geopotential height in Cluster 2. On the surface pressure map, the north Pacific high is clearly seen and the Okhotsk high is located to the southeast of the Sea of Okhotsk. The small standard deviation around the Sea of Okhotsk may indicate the constant formation of anticyclones. There are a low-pressure area and the distinct frontal zone

Fig. 15. As in Fig. 3, except for Cluster 7

Fig. 16. As in Fig. 4, except for Cluster 7.

around 35°N between the north Pacific high and the Okhotsk high. According to Fig. 19, the Yamase wind in Cluster 2 mainly appears from June to early in August, and then the fronts lying along the southern coast of Japan are considered as the Baiu fronts. The large standard deviation of pressure along around 40°N is made by the frequent passage of cyclones accompanied by the frontal zone. The 500 hPa geopotential height pattern is similar to Cluster 1, but the southern axis of westerly wind zonally streams and lies along around 35°N , corre-

sponding to the surface frontal zone. This westerly wind axis may be defined as the subtropical jet stream accompanied by the Baiu frontal zone. These stationary Baiu frontal zone and zonal upper westerly wind are the characteristics of Cluster 2.

The mean surface pressure in Cluster 3 indicates the predominant Okhotsk high and the relatively large pressure gradient around Japan (Fig. 22). The low pressure and large standard deviation areas are located east of Japan and to the south of the Korean Peninsula. They are formed by the migrating typhoons and cyclones accompanying the fronts. On the 500 hPa geopotential height field, the axis of westerly wind separates around East Mongolia (Fig. 23). The southern axis meanders and makes two distinct troughs along 130°E and 160°E , corresponding to the surface low-pressure. The northern axis also meanders and makes troughs and a ridge, but their positions differ from the southern one and a distinct ridge is found along 140°E . The surface Okhotsk high is formed to the east of this ridge. According to Fig. 19, the cases in Cluster 3 mainly appear in July and August, and then the Yamase wind in this cluster blows when the upper westerly wind meanders, the distinct Okhotsk high is formed, and the cyclones and fronts pass around Japan from late Baiu to summer.

In Cluster 4, the Okhotsk high and the north Pacific high are distinctly formed and a high pressure ranges from the Okhotsk high to the Japan Sea (Fig. 24). The frontal zone is created from South China to the north Pacific between the Okhotsk high and the north Pacific high pressures. The large standard deviation is also found to the east of 140°E between these two high-pressure areas and is formed by the

Table. 1. Features of the Yamase wind in each cluster.

Cluster	1	2	3	4	5	6	7
Easterly wind height	940 hPa	600 hPa	800 hPa	880 hPa	500 hPa	770 hPa	980 hPa
Air mass height	940 hPa	770 hPa	830 hPa	880 hPa	930 hPa	810 hPa	980 hPa
Surface temperature deviation	Small	Large	Middle	Middle	Small	Large	Small
Surface easterly wind strength	Weak	Strong	Middle	Middle	Strong	Middle	Weak
Main appearance season	Jul–Aug	Late Jun –early August	Jul–Aug	Jun–Jul	August	June	June

Fig. 17. Mean surface pressure and the distribution of fronts for Cluster 1 (0000 UTC).
This is made by using ten weather maps. The contour interval is 1 hPa. Shaded areas indicate standard deviations exceeding 5 hPa.

Fig. 18. Mean 500hPa height field for Cluster 1 (0000 UTC).
This is made by using the same ten weather maps as in Fig. 17. The contour interval is 2 gpm.

Fig. 19. Seasonal frequency of Yamase-wind days in each cluster at ten-day intervals.

passage of cyclones and fronts. According to Fig. 19, the cases in Cluster 4 mainly appear before late July, and then this frontal zone is regarded as the Baiu frontal zone. The upper westerly wind over Japan is also considered as the subtropical jet stream (Fig. 25). Both the cases of Clusters 2 and 4 frequently appear in the Baiu season, but the situations are slightly different. The axis of upper westerly wind in Cluster 4 constitutes one stream, but the axis in Cluster 2 is divided into two streams. Also, the trough around the Bering Sea located to the east rather than as for Cluster 2. These features suggest that the southward movement of Pm air mass in Cluster 4 is weaker than Cluster 2, and this may be one cause of the different situations of cold air invasion in northeastern Japan.

In Cluster 5, there is a weak Okhotsk high to the northeast of Hokkaido and two low-pressure areas in the Japan Sea and southeast of Japan (Fig. 26). These high and low pressures make a large pressure gradient around northeastern Japan and in this area the standard deviation of surface pressure is small. There is no distinct frontal zone in this cluster. The upper westerly wind streams to the north of 40°N (Fig. 27). Since a ridge is located to the north of Japan, the Pm air mass may be reluctant to move southwestward from the Sea of Okhotsk and the Bering Sea area. The cases in this cluster appear after mid-July and mainly in August (Fig. 19), and this type of Yamase wind is peculiar to the summer season.

In Cluster 6, a strong Okhotsk high is present and covers from the north of Japan Sea, Korean Peninsula to the northern part of Japan (Fig. 28). The frontal zone lies to the south of Japan, correspond-

ing to the low-pressure area between the Okhotsk high and the north Pacific high pressures. The large standard deviation of surface pressure to the east of Japan may be produced by the movement of cyclones and the variation of the strength of anticyclone. Since the Yamase-wind days in this cluster appear only in June (Fig. 19), the frontal zone lying from the South China to the north Pacific is considered as the Baiu front. On the 500 hPa geopotential height map, a deep trough is located from the south of the Bering Sea to the Japan Sea, and a ridge is formed from North China to the Sea of Okhotsk (Fig. 29). A strong upper westerly wind blows from Mongolia via the southern coast of Japan to the north Pacific, corresponding to the Baiu frontal zone. This type of Yamase wind induces a low temperature in eastern Japan in the early Baiu season; this low-temperature phenomenon is called "Tsuyuzamu" in Japan.

According to the case study by Kanno (1988), a large-scale Pm air mass is formed around the Sea of Okhotsk and the Bering Sea in June. Therefore it is thought that the Pm air mass moves southeastward along the upper trough and a large amount of sensible and latent heat is supplied by the sea surface due to the large temperature difference. Then the Yamase air mass has a thick mixed layer, as shown in Fig. 13.

The cases in Cluster 7 also appear only in June and the surface pressure and 500 hPa geopotential height patterns are similar to Cluster 6, *i.e.*, the positions of the frontal zone and the streams of the upper westerly wind are nearly the same (Figs. 30 and 31). However, the upper trough is weaker and the Okhotsk high is less distinct. Therefore the southward movement of the Pm air mass may be weaker than in Cluster 6. The pressure gradient around Japan is the weakest of all the clusters.

A conclusion is that the surface pressure pattern, front distribution, and the mean 500 hPa geopotential height field have unique characteristics in each cluster. The main appearance seasons of each cluster are summarized in Table 1. Only in June, when an upper deep trough is located from the south of the Bering Sea to the Japan Sea, do two types of Yamase wind blow; in the case of a distinct Okhotsk high, a strong and cold Yamase wind blows (Cluster 6), but in case of a weak Okhotsk high the surface easterly wind and cold air invasion are restricted in a small area (Cluster 7). According to Section 3, the former type of Yamase wind has a high easterly wind and air mass, and the latter one's are low.

Mainly in the Baiu season (from June to July), two types of Yamase wind also blow. Both have the distinct Okhotsk high and the Baiu frontal zone to the southern coast of Japan, but in the case of the upper trough located in the west of the Bering Sea a strong Yamase wind blows (Cluster 2), and in the

Fig. 20. As in Fig. 17, except for Cluster 2.

Fig. 21. As in Fig. 18, except for Cluster 2.

Fig. 22. As in Fig. 17, except for Cluster 3.

Fig. 23. As in Fig. 18, except for Cluster 3.

Fig. 24. As in Fig. 17, except for Cluster 4.

Fig. 25. As in Fig. 18, except for Cluster 4.

Fig. 26. As in Fig. 17, except for Cluster 5.

Fig. 27. As in Fig. 18, except for Cluster 5.

Fig. 28. As in Fig. 17, except for Cluster 6.

Fig. 29. As in Fig. 18, except for Cluster 6.

Fig. 30. As in Fig. 17, except for Cluster 7.

Fig. 31. As in Fig. 18, except for Cluster 7.

Fig. 32. The appearances of Yamase-wind days in each cluster from 1979 to 1993. Three-months-mean temperatures (June, July and August) at the Hachinohe weather station are shown by the solid line, and the broken line indicates the normal temperature.

case of an upper trough located in the east of the Bering Sea the Yamase wind is not so cold (Cluster 4). These different positions of upper trough may affect the southward movement of the Pm air mass, and then the Yamase wind in Cluster 2 has a high easterly wind and air mass, but those in Cluster 4 are low.

From late Baiu to summer, when the upper westerly wind streams meandering, a surface Okhotsk high is formed, and cyclones and/or fronts pass over Japan and the Yamase winds included in Clusters 1 and 3 blow; the former Yamase wind is a local type—weak surface easterly wind and small low temperature area—and latter one is of medium type. These situations may be induced by differences in strength of the Okhotsk high, its position, and the Yamase air-mass and easterly wind heights. In Cluster 1 the air mass and easterly wind heights are both low, but in Cluster 3 they are not low.

In the summer season, the Yamase wind included in Cluster 5 blows. In the case of this Yamase wind, a strong surface easterly wind blows under a large surface pressure gradient and high easterly wind, but the Pm air mass may barely move southward, and then the thin Yamase air mass induces a small low-temperature area.

The mean 500 hPa geopotential height pattern of all the clusters may be classified into Type E presented by Okawa (1973). In this type, a trough is situated over or near the Bering Sea and a ridge is located over or near East Siberia, and the surface Okhotsk high is formed under the eastern part of the ridge. We could not find the other types of upper air flow—Type N (cold air comes from the Arctic through East Siberia) and Type R (a surface anticyclone is formed accompanied by a distinct up-

per ridge)—in the mean geopotential height field. It suggests that the surface Okhotsk high is formed only under some upper air conditions, but Type E's 500 hPa geopotential height pattern is essential for the Yamase-wind.

5. Yamase-wind appearances in each year

Figure 32 shows the appearances of the Yamase wind in each year from 1979 to 1993 and the three-months-mean temperature (June, July and August) at the Hachinohe meteorological observation station. It seems that the frequency of the Yamase wind is correlated with the three-months-mean temperature, the correlation coefficient (r) between them being 0.756.

Seven years (1980–83, 1986, 1988, and 1993) had lower temperatures than normal, and especially in 1980, 1988 and 1993, the summer was very cool in northeastern Japan, causing the rice to suffer severe damage over large areas. In these cool summer years, the cases in Cluster 2 more frequently appear than the other low-temperature years. As mentioned before, the Yamase wind in Cluster 2 has a thick and cold air mass, causing low temperatures over a large area in northeastern Japan. Therefore, the appearance of the Yamase wind included in Cluster 2 may be closely connected with the cool summer. The cases in Clusters 3 and 4 also frequently appear in the cool summer years, but they are also found in other low- and high-temperature years. It is thought, therefore, that the cool summer is induced by the Yamase wind classified in Clusters 2, 3, and 4, but the Yamase wind in Cluster 2 plays an especially important role in causing a cool summer. Note that the Yamase wind in Cluster 6 also has a thick and very cold air mass, but it appears

only in June, its frequency being relatively small. Therefore it may not be connected with the cool summer.

6. Conclusion

The Yamase wind was classified by using upper-air meteorological data. A cluster analysis was performed based on the vertical structures of the Yamase air masses, which were divided into seven clusters. The features of the Yamase air masses and the main appearance seasons in each cluster are summarized in Table 1.

Only in June, when a upper deep trough is located from the south of the Bering Sea to the Japan Sea, do two types of Yamase wind blow. In one type, the Yamase air mass and easterly wind have a height of over about 800 hPa, the distinct Okhotsk high is formed, the surface easterly wind blows over northeastern Japan, and an extremely-low-temperature area spreads over the Pacific side (Cluster 6). Even on the Japan Sea side the temperature is low. In the other type, the easterly wind and Yamase air mass heights are both low (980 hPa), the surface Okhotsk high is weak and the surface easterly wind and cold air invasion are restricted to a small area (Cluster 7).

Mainly in the Baiu season (from June to July), two types of Yamase wind blow and both have a distinct Okhotsk high and a Baiu frontal zone near the southern coast of Japan. In one type, the upper trough is located in the west of the Bering Sea, the Yamase air mass and easterly wind have heights of 770 hPa and 600 hPa, the surface easterly wind blows over northeastern Japan, and an extremely low temperature area spreads over the Pacific side (Cluster 2). In other type, the upper trough is located in the east Bering Sea, the easterly wind and Yamase air mass heights are both 880 hPa, and the surface easterly wind and cold air invasion are restricted to the Pacific side (Cluster 4).

From late Baiu to summer, when the upper westerly wind streams meandering, surface Okhotsk high is formed, and cyclones and/or fronts pass over Japan, the Yamase winds included in Clusters 1 and 3 blow. The Yamase wind in Cluster 1, having the low air mass and easterly wind heights (both are 940 hPa), is the local type—surface easterly wind and low-temperature are restricted to a small area. The Yamase wind in Cluster 3 is the medium type and has an easterly wind height of about 800 hPa, the air mass height being about 830 hPa—the surface easterly wind blows over northeastern Japan but the surface temperature is not extremely low, and the cold air is effectively blocked by the central mountain range.

In the summer season, when the cyclones make a large pressure gradient around Japan, the Yamase wind having a strong surface easterly wind blows

(Cluster 5). In this case, the easterly wind blows from the surface to 500 hPa but the Yamase air mass height is low (930 hPa); then, the low-temperature area is restricted to a small area.

The mean 500 hPa geopotential height pattern of all the clusters may be classified into Type E—a trough is placed around the Bering Sea and a ridge is located around East Siberia, and the surface Okhotsk high is formed under the eastern part of the ridge—presented by Okawa (1973). Since the other types of upper airflow were not found in this study, the Type E's 500 hPa geopotential height pattern is regarded as essential for the Yamase wind.

The Yamase-wind appearances in each year indicate that the amount of the Yamase wind is correlated with the three months (June, July and August) mean temperatures at the Hachinohe meteorological observation station. The severe cool summer years (1980, 1988, 1993) are induced by the Yamase winds classified in Clusters 2, 3, and 4; however, the Yamase wind in Cluster 2 having a thick and cold air mass plays an especially important role in causing a cool summer.

The Yamase-wind appearances in each cluster show a seasonal dependence. Whereas this is a very interesting feature, its causes have not been examined, and will be investigated in the future. We believe that if the Yamase wind type can be discriminated beforehand, the low temperature area will be predicted before the crops suffer cool-weather damage.

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ヤマセ風（東北日本に吹走する低温の北東風）の気塊の鉛直構造に基づいた分類

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日本の東北地方の夏季に低温をもたらすヤマセ風について、1979年から1993年の三沢の高層気象データを用いて分類を行った。ヤマセ気塊の鉛直構造に対してクラスター分析を行い、7つに分類した。各クラスターに属するヤマセ気塊の特徴を、クラスター毎に平均して調べた。

ヤマセ風による地表の低温域は気塊の高さに比例しているが、気塊の高さは必ずしも東風の高さと一致していない。ヤマセ気塊、東風共に高い（約800 hPa以上）場合、地表では東風が東北地方全域を吹走し、強い低温域が太平洋側に認められる（クラスター2と6）。東風が高いが（約800 hPa以上）、気塊の高さが低い場合（約800 hPa以下）、東風は東北地方全域を吹走するが、地表の低温はそれほど強くはなく、寒気は山地によって効果的にブロックされる（クラスター3と5）。ヤマセ気塊、東風共に低い場合、地表の東風と低温域は太平洋側に限定される（クラスター1、4と7）。

各クラスターに属するヤマセ風の出現頻度には季節性が認められる。クラスター6と7は6月にのみ出現し、クラスター2と4は主に梅雨期に、クラスター1と3は梅雨後期から盛夏季に、またクラスター5は主に盛夏季に出現する。また、地上気圧配置、前線の頻度、および500 hPaの高度場はクラスターごとに特徴的な分布を示している。

各年ごとにヤマセ風の出現頻度を調べたところ、夏が著しく低温であった1980年、1988年、および1993年には、クラスター2、3、4のヤマセ風が多く吹走していた。しかしながら、低温かつ高さの高い気塊を伴うクラスター2に属するヤマセ風が、夏季の低温に重要な役割を担っていることが示唆された。