Seasonal Phase Lock of Temporal and Spatial Variations of the Lower Cold Air in the Winter Northern Hemisphere

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Abstract

The climatological features of temporal and spatial variations of large-scale circulation and lower cold air (LCA) in the winter northern hemisphere are investigated using 9-year mean temperature and geopotential height data, from 1980 to 1988. The large-scale circulation pattern abruptly changes in late December (the 70th pentad) and mid-February (the 9th pentad), and shows a more meandering pattern in the period between these two pentads. We define this period as the climatological 'midwinter' in the northern hemisphere.

During midwinter, LCA regions lying around the eastern part of Siberia and the Northwest Territories of Canada exhibit periodical and phase-locked variations with periods of about 25–35 days. The phase-locked migration patterns of three major LCAs in the eastern part of Siberia, Northwest Territories of Canada, and Scandinavian Peninsula in midwinter are investigated using the composite maps of 850 hPa temperature anomaly. The LCA over the Scandinavian Peninsula migrates from the high cyclonic activity area in the North Atlantic to the north side of the Tibetan Plateau. The LCA in Siberia is formed periodically with large temperature variation and migrates to the Central Pacific. The LCA over the North American Continent spreads in the meridional direction.

The phaselocking of LCA movement is closely related to the appearances of some natural seasons and singularities in Japan.

1. Introduction

The monsoon activity over East Asia has been known to have peculiar cycles. According to Lau *et al.* (1988), the summer monsoon over East Asia has 20-day and 40-day oscillations and northward propagation of major rainbands over China shows strong phaselocking. Since such phaselocking is also seen in the Bai-u over Japan (Tanaka, 1992), it may be one of the features of the East Asian summer monsoon.

In winter, on the other hand, many studies reveal periodical variations related to the winter monsoon in individual years. For instance, the low-level monsoonal surge is associated with 4–6 day period oscillations over the East China Sea, and dominated by the 20- to 30-day period oscillations over China, the East China Sea, the South China Sea, and the West

Pacific (Murakami, 1979). According to Blackmon *et al.* (1984a, b), and Lanzante (1990), 500 hPa and 700 hPa heights in the winter northern hemisphere fluctuate on the intraseasonal time scale, 10- to 30-day periods. Pan and Zhou (1985) showed that winter lower tropospheric north-south thermal gradient over East Asia, the Siberian high pressure system, and subtropical jet system vary on a time scale of 10–20 days. Pan (1987) also studied the 10- to 20-day variations of the upper tropospheric wind field over the northern hemisphere. Therefore, the winter monsoon over East Asia has peculiar cycles in individual years. However, the phaselocking of the winter monsoon on the long-term mean field has not been studied.

On the other hand, the studies of natural seasons in Japan indicated some substages of winter, such as early winter, midwinter, and late winter (Kawamura, 1973; Yoshino and Kai, 1977). In addition,

Maejima (1967), Yoshino and Fukuoka (1967), and Yamakawa (1988) investigated the seasonal variations of dominant pressure patterns over East Asia and showed some singularities in winter. Since the intraseasonal variations, substages and singularities are related to the activity of cold air outbreaks and the large-scale circulation system, it is probable that the winter monsoon over East Asia shows intraseasonal phase-locked activity. As described in Sumi and Murakami (1984), both summer and winter monsoons over East Asia are not regional but global-scale phenomena. Therefore, the phaselocking of the winter monsoon may be related to the global-scale intraseasonal variations.

The aim of this study is to clarify the climatological features, especially the seasonal phase-lock of large-scale circulation and lower cold air (LCA) in the winter northern hemisphere. In order to reveal the climatological features of wintertime circulation systems, the 9-year mean temperature and geopotential height data were used.

2. Data and analysis procedures

Once-daily (12GMT) grid point data (2.5° latitude/longitude horizontal resolution) from the European Centre for Medium-Range Weather Forecasts (ECMWF) for ten cold seasons of 1980–1988 (from November to March, include January to March in 1980 and November to December in 1988) were used in this study. The 5-day mean temperature and geopotential height at each standard isobaric surface were constructed by averaging in these years.

Temperature data at 700 hPa are not appropriate for the analysis because the height of the 700 hPa surface nearly corresponds to the upper limit of the polar continental air mass (*e.g.*, Kanno, 1991). Besides, the data at 1000 hPa are inappropriate because the highland areas around 1000 m above sea level are widely spread over the Eurasian Continent. Therefore, temperature and height data at the 850 hPa isobaric surface were used for analyzing the lower cold air. The 500 hPa height data were utilized for investigating the seasonal variations of large-scale circulation features.

The analysis procedure is as follows: The period of ‘midwinter’ is defined as one stage of the seasonal variations of large-scale circulation bounded by abrupt changes of the circulation system using the 500 hPa geopotential height field. The features of the large-scale circulation are examined by comparing the height deviations before and after midwinter. Next, temporal variations of LCA are investigated by the latitude-time and longitude-time cross sections of 850 hPa temperature, and the phase locking effect is considered. Then the southward migration of LCA is presented by the composite maps of 850 hPa temperature anomaly based on the phase

Fig. 1. Longitude-time cross section of 5-day mean 500 hPa height deviation from the seasonal mean (68–12th pentads: from December 2 to March 1) for the period from the 62nd to the 18th pentads (from October 31 to March 31). The values are 3-pentad running means averaged from 1980 to 1988 and from 47.5°N to 52.5°N . Contour interval 20 m; dashed contours and dots indicate negative values. The shaded area indicates height change gradient above 20 m/pentad.

locked cycles obtained above. Moreover, the characteristics of LCA migration are revealed by analyzing standard deviations of 850 hPa temperature and geopotential height variations. Lastly the relationships between natural seasons and/or singularities and phaselocking of the large-scale circulation are discussed.

3. Seasonal variations of 500 hPa geopotential height field

a. Definition of midwinter

Figure 1 shows a longitude-time cross section of 5-day mean 500 hPa height deviations for the periods from the 62nd to the 18th pentads (from October 31 to March 31) averaged between 52.5°N and 47.5°N , from the usual wintertime seasonal mean values from the 68th to the 12th pentads (from December 2 to March 1). Since the seasonal variations of the 500 hPa height field are clearly evident in the

mid-latitude area, the section crossing 50°N is selected for determining the climatological midwinter in the northern hemisphere.

In general, the 500 hPa heights significantly fall after the 66th pentad (after November 20) and rise after the 15th pentad (after March 12). Since the magnitudes of these changes are relatively large, they are defined as the seasonal variations of the large-scale circulation, from autumn to winter and from winter to spring.

On the other hand, about the 67–70th and the 9th pentads, 500 hPa height changes simultaneously over a wide area. Especially from the Gulf of Alaska to the east coast of the North American Continent, the height conspicuously changes and its deviations show opposite sign between the areas east and west of 110°W . As will be stated later, these changes indicate strengthening (the 67–70th pentads) and weakening (the 9th pentad) of the long wave trough and ridge. We take into consideration the large-scale circulation changes around these pentads and define the period between the 70th and the 9th pentads (from December 12 to February 14) as midwinter over the northern hemisphere.

Besides, some other distinct height changes are seen during midwinter over the Eurasian Continent, around the Gulf of Alaska, and over the North Atlantic Ocean. They suggest that the large-scale circulation changes again in the 73rd pentad.

In order to analyze the seasonal variations of large-scale circulation systems, the following three periods are selected:

- (i) from the 62nd to the 69th pentads (from October 31 to December 11) —Period-1.
- (ii) from the 70th to the 9th pentads (from December 12 to February 14) —Period-2 (midwinter).
- (iii) from the 10th to the 18th pentads (from February 15 to March 31) —Period-3.

b. Seasonal variations of mid-latitude large-scale circulation

Figure 2 depicts the mean 500 hPa height fields in Period-1, Period-2, and Period-3. The 500 hPa height deviations between two successive periods are also shown in Fig. 3.

The negative area of 500 hPa height change between Period-1 and Period-2 covers nearly the whole mid-latitude area (Fig. 3a). Over the Eurasian Continent, a large negative area (less than -60 m) is seen over Central Europe and the region between 30°N and 50°N . Since this negative zone runs nearly parallel to the westerlies, the major change occurs as an equatorward expansion of the circumpolar westerlies (Figs. 2a, 2b).

The trough located from the eastern part of Siberia to the Bering Sea intensifies because of the

height falling in the North Pacific. Positive deviations are found from the Gulf of Alaska to the northern part of the Rocky Mountains, and a distinct negative area is seen in the eastern part of North America (Fig. 3a). This change implies that the meandering of large-scale circulation from the North Pacific to the eastern part of North America is intensified in Period-2.

These deviation patterns over the Central Pacific to North America in Fig. 3a are similar to the Pacific/North American (PNA) pattern, one of the teleconnection patterns pointed out by Wallace and Gutzler (1981). Since the teleconnection pattern indicates the propagation of a steady Rossby wave, the intensification of troughs and ridge in Period-2 may affect the appearance of teleconnection patterns. According to Barnston and Livezey (1987), the emergence of teleconnection patterns except NAO (North Atlantic Oscillation) exhibit seasonal variations; the PNA pattern appears continuously from December to April and its peak is found in February. It is worth noting that this period seems to coincide with Period-2 in this study.

On the 500 hPa height deviation between Period-2 and Period-3, the large positive deviations lie around the Scandinavian Peninsula and from around Primorskii Krai (Maritime Territory) to the northern part of Japan over the Eurasian Continent (Fig. 3b). These positive deviations are similar to the Eurasian Pattern (EU) proposed by Wallace and Gutzler (1981). Such weakenings of trough and ridge over the Eurasian Continent may also influence the appearance of teleconnection patterns; however, these relationships must be investigated in the future.

Compared with the mean 500 hPa height field in Period-2, a trough located over the Scandinavian Peninsula becomes weaker to the north of 60°N and the strong westerlies indicated by small contour line spacing over East Europe are divided into two branches—to the north of 60°N and the south of 50°N —in Period-3 (Figs. 2b, 2c). According to Matsumoto (1983), the northern westerlies correspond to the Arctic frontal jet stream and southern one is the polar frontal jet stream. Since the division of jet stream and weakening of trough in Period-3 are not seen in other regions, they are the peculiar characteristics of the European region. The relationships between that characteristic change of atmospheric circulation and the seasonal variation in the European region must be examined later.

From the North Pacific to North America, a similar 500 hPa height deviation pattern between Period-1 and Period-2 is also seen (Fig. 3b) but with opposite sign, whereas negative deviations around the North Pacific are relatively weak. Therefore, large-scale circulation from the North Pacific to the North American Continent in Period-1 is nearly the

Fig. 2. Time-averaged 500 hPa height fields for the northern hemisphere averaged from 1980 to 1988: (a) 62-69th pentad mean (from October 31 to December 11: Period-1); (b) 70-9th pentad mean (from December 12 to February 14: Period-2); (c) 10-18th pentad mean (from February 15 to March 31: Period-3). Contour interval 50 m.

same as in Period-3.

The subtropical high-pressure cell over the Western Pacific spreads westward to the South China Sea in Period-1 and Period-3 shown by the 5875 gpm contour line; however, that area is receded to the east of the Philippines in Period-2. Since the winter monsoon surges over East Asia reach to the South China Sea (*e.g.* Murakami, 1979), it seems that the subtropical high-pressure over the South China Sea is weakened. Besides, it is probable that the intraseasonal variation of large-scale circulation is dynamically correlated to the rise and fall of the subtropical

high-pressure cell; however, we need to study this matter further.

4. Time variations of lower cold air

a. Latitude-time cross section

The time variations of LCA are investigated using the meridional section crossing the eastern part of Siberia in which the coldest air mass in the northern hemisphere is formed. In this chapter, this low temperature area is recognized as the source region of LCA, and the LCA is considered to be synonymous with the cold air mass.

Fig. 3. Time-averaged 500 hPa height differences for the northern hemisphere averaged from 1980 to 1988: (a) 70-9th pentad mean (Period-2) minus 62-69th pentads mean (Period-1); (b) 10-18th pentad mean (Period-3) minus 70-9th pentads mean (Period-2). Contour interval 20 m; dashed contours indicate negative values; dots indicate greater than 60 m and less than -60 m.

Figure 4 shows the latitude-time cross section of 5-day mean 850 hPa temperature for the period from the 62nd to the 18th pentads (from October 31 to March 31) averaged between 130°E and 140°E. A cold air under -22.5°C (LCA) is seen from the 63rd

Fig. 4. Latitude-time cross section of 5-day mean 850 hPa temperature for the period from the 62nd to the 18th pentads (from October 31 to March 31) averaged from 1980 to 1988 and from 130°E to 140°E. Contour interval 2.5°C; dashed contours and dots indicate negative values.

to the 14th pentads (from November 5 to March 11) about 55-70°N, and it corresponds to the polar continental (Pc) air mass formed by surface radiative cooling. Periodic strengthening and weakening cycles of LCA are found in midwinter; the LCA becomes colder in the 70-2nd and the 4-7th pentads, and relatively weaker in the 3rd and after the 9th pentads. Also before and after midwinter, the LCA turns colder in the 67th and the 11-13th pentads. After the 15th pentad (after March 12), the LCA becomes very weak. According to Kanno (1991), the stability of Pc air mass in the eastern part of the Eurasian Continent is rapidly reduced in late February and the temperature largely rises from late February to early March in the case of 1985. Therefore, it is probable that the stability of LCA is modified about the 15th pentad.

On the other hand, a large meridional temperature gradient is seen between the southern edge of LCA and 20°N. The LCA may be modified in that area. This air mass modification zone exhibits clear seasonal variations; southward movement in Period-1 and northward movement in Period-3; however, the cyclic variations consistent with that of LCA are not obvious.

b. Longitude-time cross section

Figure 5 shows the longitude-time cross section of 5-day mean 850 hPa temperature for the periods from the 62nd to the 18th pentads averaged between 62.5°N and 67.5°N. Since the periodical variations of LCA are clearly seen, this latitudinal section is selected.

The LCA is formed around the eastern part of Siberia (130-150°E) as shown in Fig. 4. Another LCA is recognized around the Northwest Territories of Canada (60°W-110°W), but the temperature is

Fig. 5. Longitude-time cross section of 5-day mean 850 hPa temperature for the period from the 62nd to the 18th pentads (from October 31 to March 31) averaged from 1980 to 1988 and from 62.5°N to 67.5°N. Contour interval 2.5°C; dots indicate less than -10°C.

higher than that in Siberia. This LCA also exhibits periodical variations.

Moreover, a westward spreading of the low-temperature area is found from the eastern part of the Scandinavian Peninsula to the western part of Siberia (30°E–80°E) with peaks around the 70th, the 2nd, the 6th, and the 12th pentads. According

to Matsumoto (1983), this low-temperature area corresponds to the polar air mass located between the Arctic frontal zone and the polar frontal zone.

A comparison of the time variations of the two LCAs, around the eastern part of Siberia and the Northwest Territories of Canada, shows that the latter is strengthened in the 64–65th pentads and the former is intensified tentatively in the 67th pentad. Therefore, the LCA variations are not simultaneous between the two regions before midwinter.

In midwinter, the LCA in Siberia becomes coldest about the 72nd pentad and then rapidly weakens in the 3rd pentad. Also, the LCA in Canada becomes coldest in the 73–1st pentads and weakens in the 3–4th pentads. The LCA in Siberia is strengthened again in the 6th pentad and that in Canada is intensified in the 7–8th pentads, and then they both weaken at the same time in the 9th pentad. It is supposed that both LCAs simultaneously intensify and decay for periods of about 25–35 days in midwinter. The westward spreading of low-temperature areas between 30°E and 80°E also show the nearly simultaneous periodical variation of the two LCAs.

The last strengthening of the LCA is found in the 12th pentad in Siberia and the 14th pentad in Canada, and then both LCAs weaken simultaneously in the 15–16th pentads.

c. Seasonal and intraseasonal variations of 850 hPa temperature

Figure 6 shows the temporal variations of 850 hPa temperature in the northeastern part of Siberia and Northwestern Territories of Canada. The smooth curves of 9-pentad running mean temperatures indicate the seasonal variations. The magnitude of temperature variation in Siberia is larger and the lowest peak appears earlier than that in Canada.

Fig. 6. Temporal variations of 850 hPa temperatures in the northeastern part of Siberia (rectangle from 120°E, 70°N to 150°E, 60°N) and Northwestern Territories of Canada (from 60°W, 70°N to 90°W, 60°N). The smooth curves show 9-pentad running mean values and the others depict 3-pentad running means. Shadings indicate the differences between these values.

Fig. 7. 5-day mean 850 hPa temperature deviation from the midwinter mean for the northern hemisphere averaged from 1980 to 1988: (a) Category-1 (pentads 1 and 6); (b) Category-2 (pentads 2 and 7); (c) Category-3 (pentads 3 and 8); (d) Category-4 (pentads 4 and 9); (e) Category-5 (pentads 5 and 10). Contour interval 0.5°C ; dashed contours and dots indicate negative values.

The curves of 3-pentad running mean temperature show short term variations, with about 6-pentad period, which are clearly seen during the winter half year. These variations are different from the seasonal variations, and recognized as the intraseasonal variations. The principal intraseasonal variations of temperature in Canada appear more frequently from the 63rd to the 26th pentads (from November 5 to May 10). In Siberia, they are found from the 70th pentad, corresponding to the beginning of midwinter, to the 15th pentad (from Decem-

ber 12 to March 16). In midwinter, two relatively cold periods and a warm one (1.5 cycles) are seen in both areas. This implies that the intensification and decay of LCA are phase-locked. Hence, we investigate the spatial pattern of LCA variations in the next chapter.

5. Lower cold air migration

a. Spatial pattern of lower cold air migration

The patterns of LCA migration in midwinter are investigated using the temperature anomalies. In

Fig. 7. (Continued)

order to emphasize the common features of LCA's spatial variations, temperature anomalies are composed of two cycles—from the 1st to the 5th pentads and from the 6th to the 10th pentads. These two cycles are selected in consideration of the time variations of LCA in Figs. 4 and 5, and 5-day mean temperature anomaly distributions (figures are not shown).

Figure 7 shows the composite maps of 5-day mean 850 hPa temperature anomaly, from Category-1 (the 1st and the 6th pentads) to Category-5 (the 5th and the 10th pentads), from the midwinter mean over the northern hemisphere.

In Category-1, large negative areas with temperature anomaly less than -1°C are found over the Scandinavian Peninsula, the eastern part of Siberia, from the Kamchatka Peninsula to the West Pacific, to the south of Alaska Bay, Northwestern Territories of Canada, and the Florida Peninsula (Fig. 7a). Since this category nearly corresponds to the periods of intensification of LCA, the negative areas in Siberia and Canada are the same as the two LCAs shown in Fig. 5. Also, the negative area over the Scandinavian Peninsula coincides with the westward spreading of low-temperature area (polar air mass) in Fig. 5. Since the migrations of the above-mentioned three negative areas are prominent, we consider them as the major LCAs, and analyze and trace their movements.

The LCA over the Scandinavian Peninsula ('A' in Fig. 7) moves southward and its center is located around Central Europe in Category-2 (Fig. 7b). In Category-3, it moves southeastward to the area from the Black Sea to the Aral Sea (Fig. 7c), and reaches the north side of the Tibetan Plateau with large neg-

Fig. 8. Standard deviations of 5-day mean 850 hPa temperature in the periods from the 70th to the 9th pentad (from December 12 to February 14) for the northern hemisphere from 1980 to 1988. Contour interval 1°C ; dots indicate greater than 2°C .

ative anomaly (less than -2°C) in Category-4 (Fig. 7d); it seems that the LCA is dammed up by the Tibetan Plateau. In Category-5, part of the LCA migrates southeastward along the eastern periphery of the Tibetan Plateau (A' in Fig. 7e); it looks like the cold air outbreak described by Sumi and Murakami (1984).

The LCA in Siberia ('B' in Fig. 7) moves south-southeastward to the east coast of the Eurasian Continent and over the Japan Sea in Category-2. The movement velocity is nearly consistent with that of the Siberian High, which takes about 4 days to pass over China, indicated by Ding and Krishnamurti (1987). This LCA spreads from the Korean Peninsula to the Pacific in Category-3, and spreads further with increasing negative anomaly from the eastern part of Japan to the Pacific in Category-4. In Category-5, the LCA remains east of Japan with a large negative anomaly. The northeastern part of Japan is covered with a negative area less than -1°C from Category-2 through 5, so this region is under the influence of the LCA for relatively a long time.

The LCA in Northwestern Territories of Canada ('C' in Fig. 7) moves southeastward and spreads from the Hudson Bay to the western side of the Rocky Mountains in Category-2. In Category-3, the LCA spreads from the west of Greenland to the east coast of North America in the meridional direction, and then it moves eastward over the Atlantic

Fig. 9. Standard deviations of 5-day mean 850 hPa height in the periods from the 70th to the 9th pentads (from December 12 to February 14) for the northern hemisphere from 1980 to 1988. Contour interval 10 m; dots indicate greater than 10 m.

Ocean from Category-4 to Category-5. The absence of east-west oriented mountains, such as the Tibetan Plateau, may produce the meridional spreading style of outbreak.

b. Characteristics of LCA movements

Figure 8 depicts the standard deviations of 5-day mean 850 hPa temperatures in midwinter for the nine years. The 850 hPa geopotential height deviations are also shown in Fig. 9.

To see the temperature standard deviations (σt) along the track of LCA over the Eurasian Continent, σt on the north side of the Tibetan Plateau is more than 4°C (Fig. 8). The periodical passing of LCAs may produce the relatively large σt . From the northern part of the Atlantic Ocean to the western part of Siberia, the height standard deviations (σh) exceed 80 m (Fig. 9). According to Klein (1957), many cyclones are located in these areas, so large height deviations may be due to the large cyclonic activity. Besides, the largest σt on the Eurasian Continent, more than 6°C , is found to the north of Lake Baikal. Since this area corresponds to the air mass source region, it may be due to the periodical formation of LCA. The temperature variation by the periodical LCA formation is larger than that by the LCA movement over the Eurasian Continent.

The largest σt (greater than 6°C) in the northern hemisphere is seen from Alaska to the eastern

side of the Rocky Mountains. According to Quiroz (1984), the surface temperature in the eastern side of the Rocky Mountains indicates large departure from normal during severe cold winter (1983–84). So, the area from Alaska to the eastern side of the Rocky mountains coincides with the track of LCA, and the large σt in this area is due to the frequent southeastward movement of LCAs. Large σh are found around the Bering Sea, Alaska, and the Gulf of Alaska, and they are also produced by the large cyclonic activity (see Klein, 1957).

Compared with the σh around the east coast of the North American Continent, the σh around Japan are relatively small (less than 40 m). This may be because of the continuous outbreaks of LCA around Japan.

In the Arctic Ocean, large σh and small σt are found. According to Keegan (1958), and Serreze and Barry (1988), synoptic activity in the Arctic is not small. So, it may produce the large height fluctuations. However, the upper air observation data are very few in the Arctic Ocean, so the relationships between the synoptic activity and the height fluctuation cannot be confirmed.

6. Discussion

According to Sumi and Murakami (1984), the cold air outbreak in East Asia is closely related to the eastward propagating long-periodic trough and ridge system. It is probable that the phase-locked movements of LCA indicate such a trough and ridge system to be also phase-locked in midwinter. Ding and Krishnamurti (1987) showed that the cold air outbreak in East Asia produces a variation of planetary-scale circulation and is related to the rainfall variability around the equatorial Pacific. Also, Matsumoto (1990) divided the global tropical seasons in late December. Therefore, the phase-locked cold air outbreaks may be related to the large-scale circulation in the global tropics. These hypotheses need to be confirmed in the future.

Compared with Period-2—from the 70th pentad (December 12–16) to the 9th pentad (February 10–14)—the winter season of the natural seasons when they are divided into four to six in Japan begins 2–3 pentads earlier and ends 2–3 pentads later (Maejima, 1967; Yoshino and Kai, 1977; Yamakawa, 1988). However, the substage of winter, between December 29 and February 15 defined by Kawamura (1973), and another substage of winter, between December 26 and January 31 defined by Yoshino and Kai (1977) are mostly included in Period-2 of this study. Therefore, the relatively strong meandering pattern of the large-scale circulation in midwinter may produce the coldest period of winter in Japan.

According to Yamakawa (1988), the winter-type surface pressure pattern appears most frequently and its annual standard deviation is smallest in

the 73rd pentad in the last forty-five years. In the present study, the LCA in Siberia is coldest in this pentad. Therefore, it is probable that the Siberian anticyclone is frequently formed and produce the winter-type pressure pattern in the 73rd pentad. Also, Yoshino and Fukuoka (1967) showed a rapid decrease of the winter-type pressure pattern in the 8th pentad, which is nearly consistent with the end of midwinter defined in this study. So, the end of LCA movement may lead the rapid decrease of winter-type pressure pattern.

On the other hand, Maejima (1967) showed the singularity of the winter-type pressure pattern appearing on January 24. Yoshino and Fukuoka (1967) pointed out the same singularity in the 5th pentad—January 21–25. These periods correspond to the last category of the LCA movement cycle; the LCA located to the east of Japan, and they do not agree with the position of LCA.

According to Jones (1988), annual mean temperatures over the northern hemisphere in the period from 1980 to 1987 except for 1985 used in this study are above the means from 1951 to 1970. Besides, in the interannual variations of natural seasons over East Asia, the winter from 1971 to 1985 begins earlier and ends later than that from 1941 to 1970 (Yamakawa, 1988). Since Maejima (1967) and Yoshino and Fukuoka (1967) used meteorological data before the 1970's, it seems that the differences between the singularities of the winter-type pressure pattern appearing and the positions of LCA in this study are due to such interannual variations.

Consequently, the phaselocking of LCA movement is closely related to the appearances of some natural seasons and singularities in Japan. However, the climatic change in recent several decades may produce the secular change of natural seasons and singularities, and the further study is needed on this matter.

In this study, the climatological features of LCA are investigated using 9-year mean meteorological data. However, the El Niño years of 1982–83 and 1986–87 are included in those years. So, we will investigate the differences of LCA's features between the El Niño years and the other years, considering warm and cold winters in Japan, in the future.

7. Summary and conclusions

The climatological features of temporal and spatial variations of large-scale circulation and lower cold air (LCA) in the winter northern hemisphere are investigated using 9-year mean temperature and geopotential height data from 1980 to 1988.

The 500 hPa height deviations over the continents and North Pacific abruptly change around the 70th and the 9th pentads. Since these variations indicate a change of the large-scale circulation pattern, the period between the 70th and the 9th pentads is defined as 'midwinter' in the northern hemisphere.

The large-scale circulation in midwinter exhibits a relatively strong meandering pattern from the Pacific to North America. Due to the intensification of troughs and ridge in midwinter, the height deviations between before midwinter (Period-1) and midwinter (Period-2), and between Period-2 and after midwinter (Period-3) indicate a PNA-like pattern around the North American Continent. The EU-like height deviation pattern is also seen over the Eurasian Continent between Period-2 and Period-3. Such seasonal change of circulation pattern may be related to the seasonal variations of teleconnection pattern appearances. The large-scale circulation patterns in Period-1 and Period-3 are not the same over the European region.

During midwinter, LCA regions lying around the eastern part of Siberia and Northwest Territories in Canada are defined on the cross sections of 850 hPa temperature. These LCAs exhibit periodical and phase-locked variations, and 1.5 cycles of strengthening and weakening with periods of about 25–35 days are found in midwinter. These intraseasonal variations are clearly distinguished from the seasonal changes on the seasonal curves of 850 hPa temperature in both areas.

The phase-locked migration patterns of three major LCAs around the eastern part of Siberia, Northwest Territories of Canada, and the Scandinavian Peninsula in midwinter are investigated using the composite maps of 850 hPa temperature anomaly from Category-1 (the 1st and the 6th pentads) to Category-5 (the 5th and the 10th pentads). The LCA over the Scandinavian Peninsula migrates from the high cyclonic activity area in the North Atlantic to the north side of the Tibetan Plateau. The LCA in Siberia is formed periodically with large temperature variation and migrates to the Pacific. The LCA spreads in the meridional direction over North America. The absence of east-west oriented mountains, such as the Tibetan Plateau, on the North American Continent may produce the meridional spreading style of outbreak.

The relatively strong meandering pattern of large-scale circulation in midwinter may produce the coldest period of winter in Japan. Also, it seems that the Siberian anticyclone is frequently formed and produce the winter-type pressure pattern in the 73rd pentad, and the end of LCA movement leads the rapid decrease of winter-type pressure pattern. So, the phaselocking of LCA movement is closely related to the appearances of some natural seasons and singularities in Japan. However, the climatic change in recent several decades may produce the secular change of natural seasons and singularities, and the further study is needed on this matter.

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冬季北半球における下層寒気の時空間変動の季節的な位相固定

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北半球冬季における大規模な大気循環と下層寒気の時空間変動の気候学的特性について、1980年から1988年までの9年平均気温と等圧面高度データを用いて解析した。大気の大規模な循環パターンは12月下旬(第70半旬)と2月中旬(第9半旬)に不連続的に変化しており、その間の期間では南北流がその前後よりも強まっていた。そこでこの70-9半旬の期間を北半球における気候学的な‘真冬’(midwinter)と定義した。

mid-winterの期間中、シベリア東部とカナダの北西地方に下層寒気が存在しており、約25-35日で周期的かつ位相が固定された変化が認められた。

3つの主要な下層寒気(シベリア東部付近、カナダの北西地方、およびスカンジナビア半島付近に存在しているもの)について、それらの位相の固定された動きを850 mb気温アノマリーの合成図を用いて検討した。スカンジナビア半島付近にあった下層寒気は北大西洋の低気圧活動が活発な地域からチベット高原の北側まで移動していた。また、シベリアの寒気は気温変動が大きく、周期的に形成され、太平洋中部まで移動していた。さらに、北米大陸では下層寒気が南北方向にのびた形で吹き出していた。

日本の従来の研究による自然季節の冬のサブステージ(真冬)は、ほとんどが本研究のmid-winterに含まれていた。従って、mid-winterの期間の下層寒気の吹き出しをともなった相対的に南北流の強い循環が日本に冬の最盛期をもたらすと考えられる。また、第73半旬の下層寒気の強まりはシベリア高気圧の形成と冬型気圧配置のシンギュラリティーを、mid-winterの終了は冬型気圧配置の急減をもたらすことが考えられる。このように、位相の固定された下層寒気の変動は日本付近の自然季節やシンギュラリティーのうちのいくつかについてその要因を説明できると考えられる。しかしながら最近数十年の気候変化は自然季節やシンギュラリティーにも経年変化をもたらしている可能性があり、この点に関しては今後解析する必要がある。