Warm-Core Events of the Arctic Winters Appeared in the Annual March of the Monthly Mean Air Temperatures北極域の月平均気温変化に現れる冬季のウォームコア現象

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Warm-Core Events of the Arctic Winters Appeared in the Annual March of the Monthly Mean Air Temperatures

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Abstract : A warm-core event is the warm spell observed during the coreless type winter of the annual march of surface temperature in the high latitudes. We can explain some possible causes for the warm spell : 1) the large scale warm advection around the action centers such as the Aleutian and the Icelandic lows, 2) passing of cyclonic disturbances that break the strong surface temperature inversion, and, 3) existence of cut-off warm anticyclones that derived from blocking ridges. This paper shows the geographical distribution of occurrence frequency of the warm-core events in the northern hemisphere by using the monthly mean temperature data of NMC octagonal grids. Warm-core events are found not only on the surface grids but also on the 700hPa and 500hPa grids. The geographical distribution of each grid system shows a same pattern, so that the large scale warm advection is the most important cause for the warm-core events.
Key words : warm core, coreless winter, Arctic, blocking, air temperature.

1 Introduction

The annual march of monthly mean surface temperatures in the high latitudes often shows the *coreless* type in winter. In the Antarctic, we can observe the typical coreless winters that associate with the strong surface temperature inversion. Kawaguchi (1979) pointed out one possible cause that the upward terrestrial radiation balances with the downward atmospheric radiation during the polar night, so that the monthly mean surface temperatures stagnate around a bottom value.

Although the large scale topography of the Arctic is quite reverse to the Antarctic, coreless winters also occur in the northern hemisphere. In this situation, the vertical temperature profile shows a strong surface inversion (i.g., Streten, 1969 ; Kahl, 1990). Therefore, one of the most important factors controlling the Arctic winter temperature field is the downward long wave radiation. This factor is strongly influenced by the behavior of the polar vortex through the variation of temperature, humidity, and cloudiness (Overland *et al.*, 1997).

Vowinckel and Orvig (1970) stated that cold spells over the Arctic Ocean are not caused by the cold advection but by the radiative cooling, and warm spells are caused by cyclones that distract the inversion. They also mentioned that this surface inversion is ordinarily intensified by the upper-level warm advection.

The warm advection, however, occasionally raises surface temperature and causes a warm spell. Therefore they concluded that the Arctic surface inversion is a complex phenomenon. Recently, Serreze *et al.* (1992) analyzed station data including aerological soundings and the Russian drifting-ice stations. They showed that temperature inversions usually appear in the Eurasian side of the Arctic Basin and the thickness of inversion layer is about 1000m in winter.

Figure 1 shows the three types of surface temperature change in winter. The *cold-core* type is ordinary in the middle latitudes, and the *coreless* type is typical in the polar region. When a warm spell of relatively long term is observed in the polar winter, it makes a *warm-core* upon the flat coreless line (hereafter referred to as *warm-core event*).

Some meteorological stations around the Bering Sea (in January) and the Barents Sea (in February) show the warm-core as the climatic values of monthly mean surface temperature. For example, Shiraiwa and Sawagaki (1992) observed a warm-core event during the winter of 1990 in Spitsbergen.

Rubinshteyn (1962) showed the occurrence frequency map of the warm-core events by using monthly mean temperature of 110 stations around the Arctic Basin. He figured out two high frequency areas: the Norwegian Sea (from the east coast of Greenland to the west coast of Novaya Zemlya), and the Bering Sea. He also reviewed the discussion of the cause for warm-core events. He summarized three principal mechanisms:

- the warm advection from the lower latitudes,
- the sensible heat transport from the Arctic Ocean through the sea ice,
- the release of latent heat at the sea ice formation.

The warm advection is the only one possible cause for the warm-core among them, because we can observe warm-core events outside the Arctic Basin and

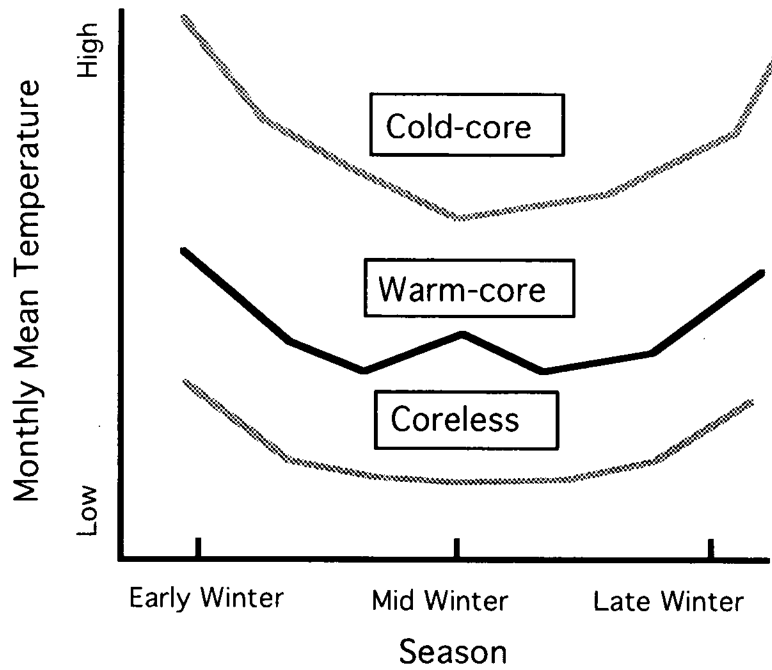

Figure 1 Schematics for the warm-core type temperature change.
The cold-core type is ordinary in the middle latitudes and the coreless is typical in the Arctic region.

even in the inland region of the continents.

The purpose of this paper is to show the temporal and spatial characteristics of the warm-core events in the Arctic region. In order to discuss the structure of large-scale warm advection, the author paid a special attention to recognize the geographical distribution of occurrence frequency in the upper troposphere, and he extends the area of analysis up to the middle latitudes of the northern hemisphere.

2 Data and the warm-core definition

The data used in this study are the NMC (National Meteorological Center, USA) octagonal grids of the monthly mean temperature of the northern hemisphere. The author used the temperature of three levels (surface, 700hPa, and 500hPa) for 22 winter seasons from 1965-66 to 1986-87. The winter season is defined as the 5-month period from November to March. We ordinarily define the northern hemisphere winter season as the 3-month period from December to February. In the present analysis the author focused on the annual march of temperature in the Arctic region, so that he added November and March.

Of course, the term *warm-core* means a *warm-core type Arctic winter*, then the term is to be used only for the high latitudes. A warm-core event in the Arctic region implies the existence of the large-scale positive temperature anomaly that may extend into the middle latitudes. This means that warm spells of the middle latitudes closely relate to the Arctic warm-core. The author named both Arctic warm-cores and warm spells in the middle latitudes as high temperature events. A high temperature event for a month in a winter season at a given grid point meets the following simple condition:

$$t_{m-1} < t_m \quad \text{and} \quad t_m > t_{m+1}.$$

In the above expression, t is the monthly mean temperature of one grid point, and the subscripts m-1, m, and m+1 denote the previous month, the very month (from November to March), and the following month respectively.

The above procedure may be too descriptive to make a physical image. The author gives an example that shows the spatial relationships among the geopotential height, temperature anomaly, and high temperature events. Figure 2 shows the monthly mean height and temperature anomaly of 500hPa surface for January 1977. The most striking feature of this month was the simultaneously developed blocking ridges in the Atlantic and the Pacific. These two ridges coupled over the Arctic Ocean and became into a single anticyclonic system (Fig. 2 left).

By using the station data, Umemoto (1985) showed that this synoptic event produced an extremely cold weather over the broad area of East Asia, and at the same time, a warm weather over the high latitudes. The NMC grids of 500hPa level for January 1977 also indicate the large positive temperature anomaly over the high latitudes (Fig. 2 right). Relatively large anomaly areas (for example, above +6 degree) are situated in the positions of the two blocking ridges (the Northeast Pacific and the Northwest Atlantic) and of the cutoff high over the Arctic Basin.

Figure 3 shows the geographical distribution of high temperature events for January 1977. High temperature events of the 500hPa level show several

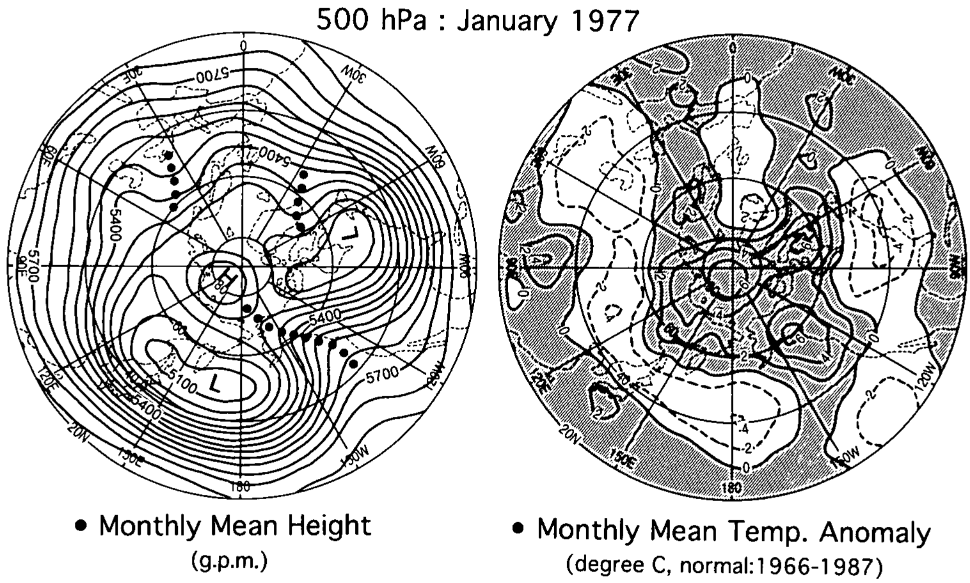

Figure 2 The monthly mean geopotential height and monthly mean temperature anomaly of the 500hPa surface for January 1977 : (left) height in meter, and the dotted lines show the ridges, (right) contours drown in every 2 degrees, shaded area shows positive anomalies.

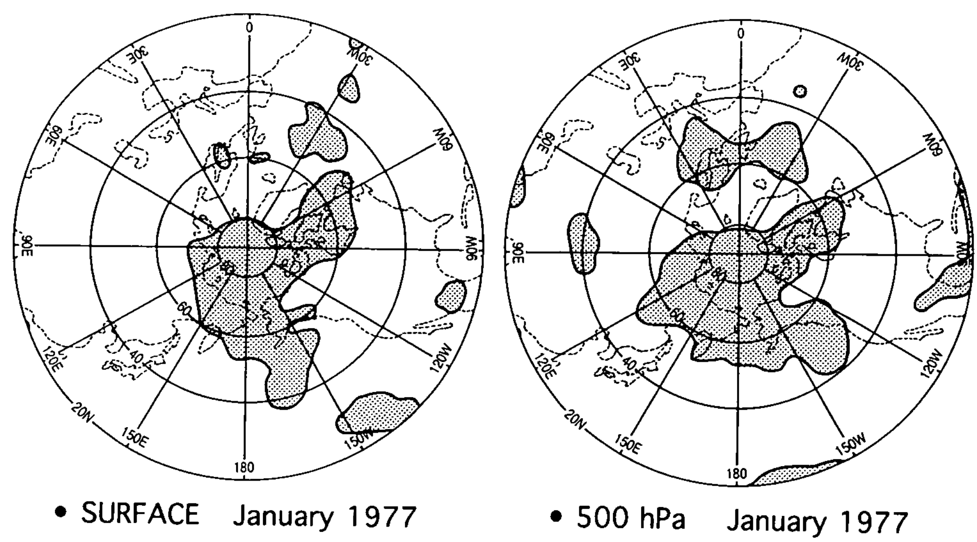

Figure 3 High temperature events occurred in January 1977. The grid points with the record of high temperature event were enclosed by lines and shaded.

expansions of areas corresponding to the large positive temperature anomaly over the high latitudes (Fig. 2 right). Both of the surface and the 500hPa charts show a very similar image over the Arctic, therefore the author considers that the statistically defined high temperature events (this means warm-core events in the Arctic) reflect a substantial atmospheric system of the synoptic scale.

3 Geographical Distribution of Warm-core Events

High temperature events are detected at all points of the NMC octagonal grid system for 22 winters. One octagonal grid contains 1977 points, but some points outside the latitudinal circle of 20N are omitted because of presentation. Figures 4, 5, and 6 show the geographical distribution of occurrence frequencies. In these figures, the author did not use any kinds of area-normalization or spatial smoothing but just calculated the occurrence ratio (times of occurrence are divided by 22). Contours are drawn in every 10% and shaded parts show the area with the value above 30%.

a) Surface

Many high temperature events occurred throughout the winter, but the frequency is very low in November. There are two high frequency areas in the Arctic region for January (Fig. 4 c) : the first one centers on the Bering Strait and it covers a broad area of the East Siberia and Alaska sector, the second is situated around Greenland. Both of these show the values of 40% or more.

A small peak can be seen to the north of Novaya Zemlya. On the other hand, high temperature events of the middle latitudes occurred in the East Pacific and the East Atlantic Oceans. The peak of the East Pacific seems to be a part of the high latitudes warm-core area. However, the peak of the East Atlantic seems to have no relation to the warm-core around Greenland.

In February (Fig. 4 d), the situation is totally different. Only one major area of the warm-core appears over the Norwegian Sea and the Greenland Sea. Another small peak is in the east part of Alaska and it covers the coastal area of the Gulf of Alaska. Besides this, we can not find any notable areas of high temperature event. In other months, the frequency of warm-core is low. One exception is the Barents Sea in March (Fig. 4 e).

We can see some high frequency areas of high temperature events in the low latitudes too (for example, the East Pacific Ocean of November, the middle

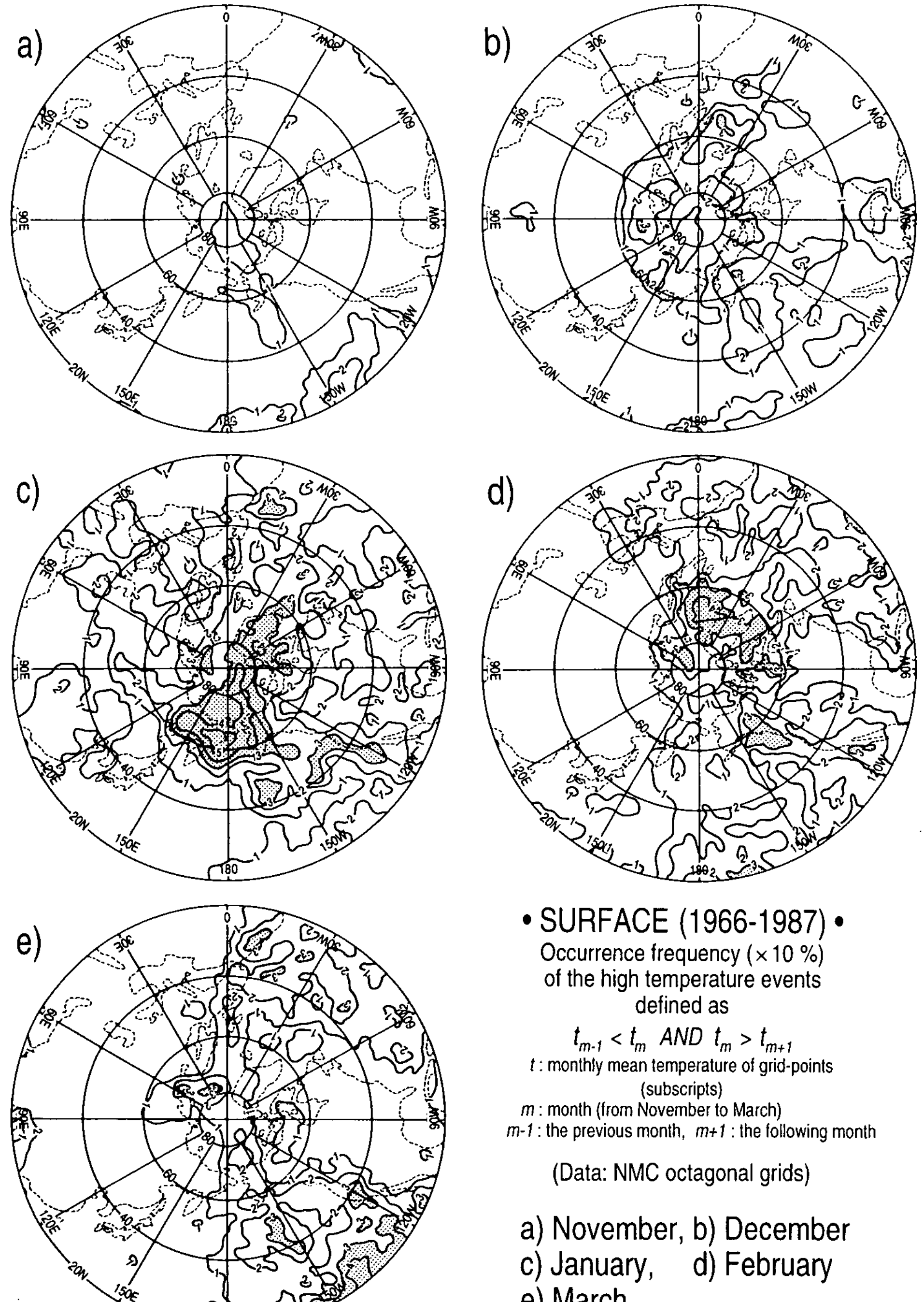

Figure 4 Surface occurrence frequency of the high temperature events in the northern hemisphere. Contours were drawn in every 10 percent, and a shaded area shows above 30%.

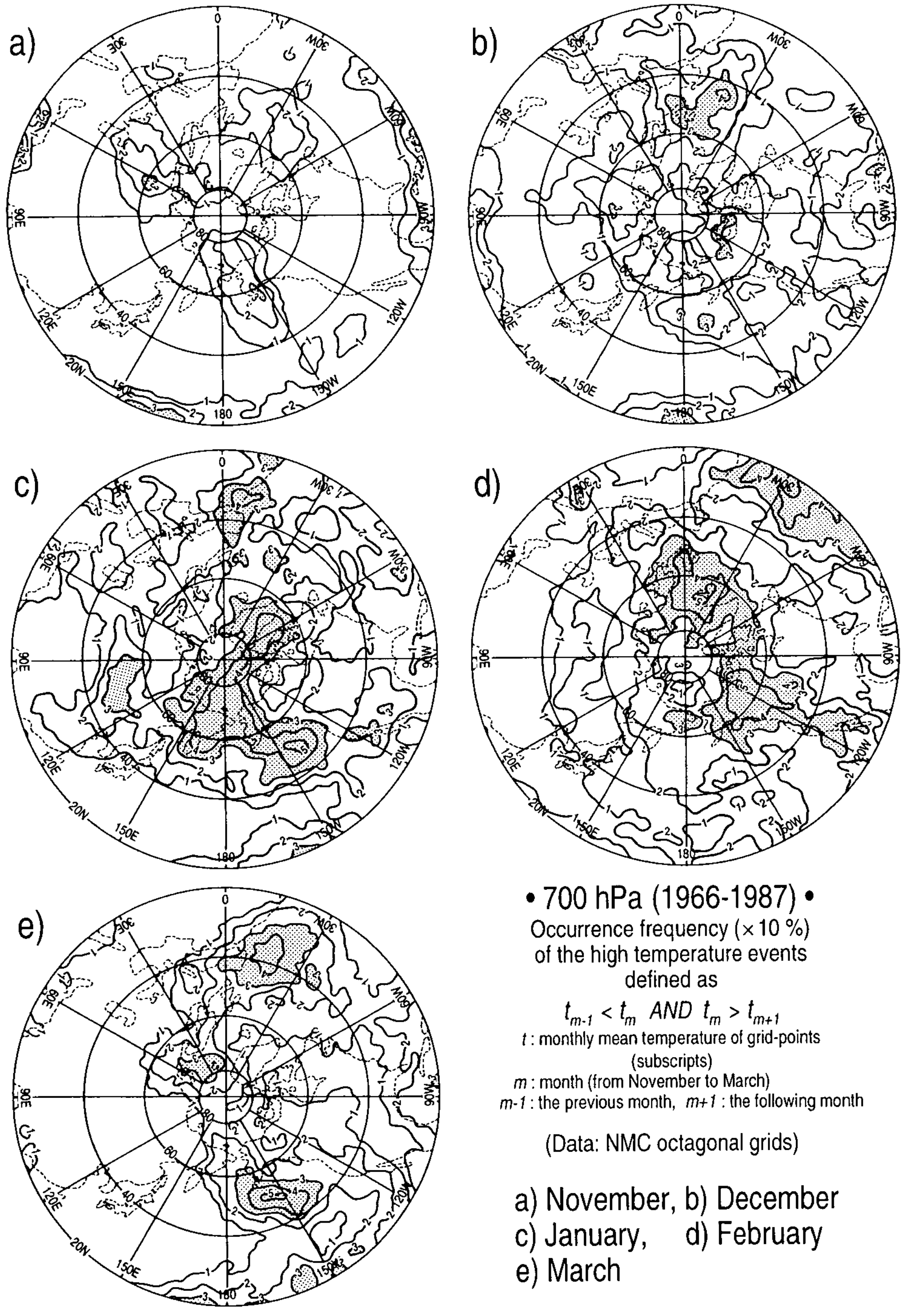

Figure 5 700hPa level occurrence frequency of the high temperature events in the northern hemisphere. Contours were drawn in every 10 percent, and a shaded area shows above 30%.

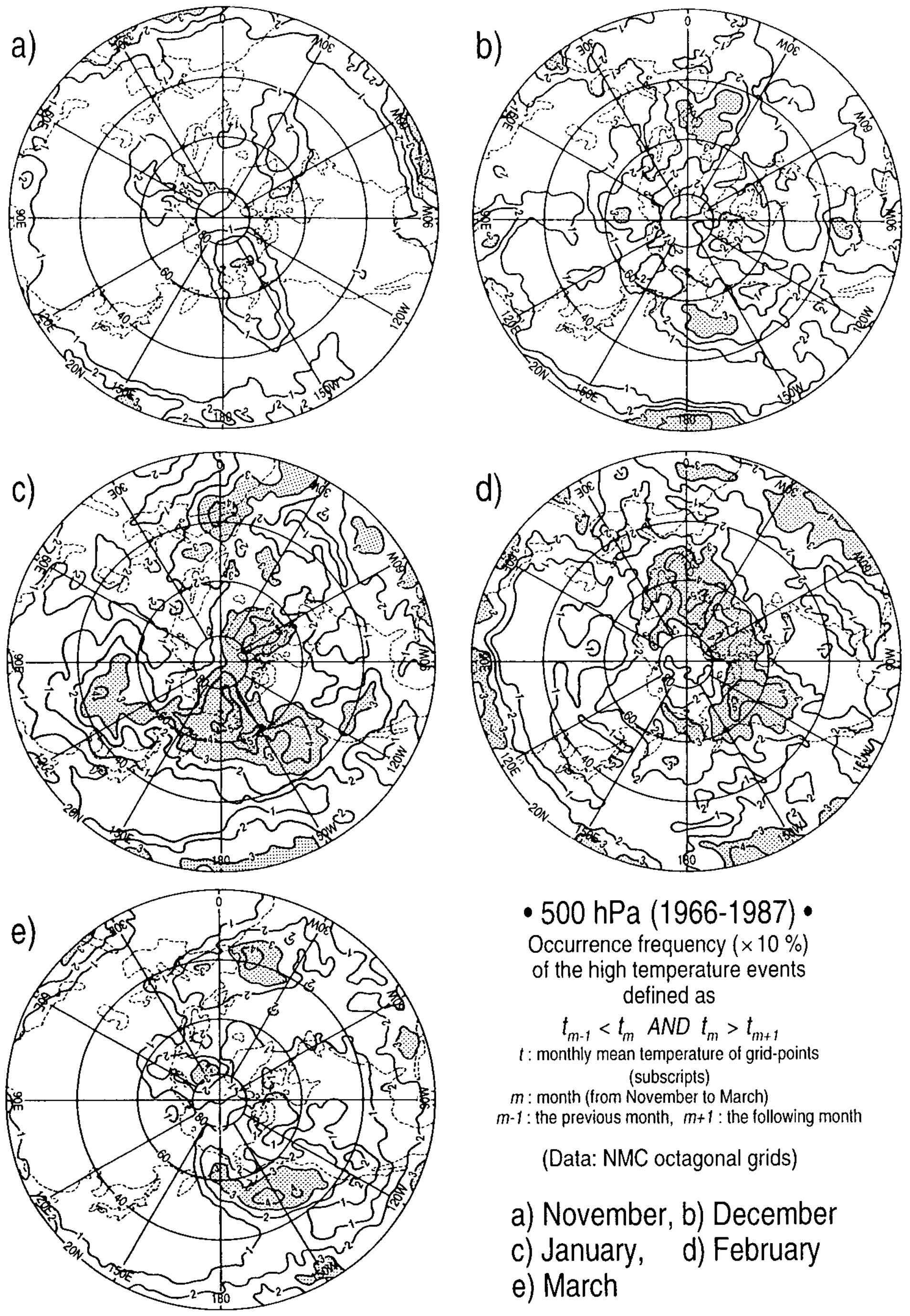

Figure 6 500hPa level occurrence frequency of the high temperature events in the northern hemisphere. Contours were drawn in every 10 percent, and a shaded area shows above 30%.

Atlantic Ocean of February, etc.). But these areas have no direct relations to the atmospheric circulation of the Arctic. Moreover, the procedure for finding high temperature events used in this paper may be meaningless for the Tropics. The author, therefore did not take these peaks into consideration on the warm-core events.

b) Upper levels

The distribution of high temperature events of 700hPa and 500hPa in November shows a familiar pattern that recalls us to the circumpolar flow of zonal wave-number three (Figs. 5 a and 6 a). High frequency areas are situated in the East Pacific sector centered in Alaska, to the south of Greenland, and along the Ural Mountains.

In December, we can see two major areas of high frequency in the middle latitudes of 500hPa level (Fig. 6 b): the North Atlantic Ocean and the North Pacific Ocean. The North Atlantic one is marked in the 700hPa level too, but the North Pacific one is somewhat obscure in that level (Fig. 5 b). These two areas are not notable in the surface chart (Fig. 4 b).

In January, a high frequency area of warm-core events exists in the Arctic (Figs. 5 c and 6 c). The distribution pattern is similar to the surface chart. In the middle latitudes, a high value area in the northeastern Pacific extends to the Arctic through Alaska. Two other high frequency areas are distinguished over Mongolia and the southwest part of Europe.

In February (Figs. 5 d and 6 d), we can see a broad area with the higher value of warm-core events over the North American side of the Arctic. It covers from Alaska to the northwestern Europe through the Canadian Arctic. The westernmost part of the area (i.e., around Alaska) of 700hPa chart (Fig. 5 d) extends southward to the middle latitudes of the west coast of the North America.

The distribution of high temperature events of March shows three peaks (Figs. 3 e and 6 e). A relatively small area of the warm-core events appears over the Barents Sea. The other two are situated in the middle latitudes of the North Pacific and the North Atlantic. Each of the peaks takes somewhat east positions in comparison with January.

4 Discussions

The distribution of warm-core events in the Arctic shows a striking feature that the position of high value area seems to sift anticlockwise by about 60 degrees from January to February. The Atlantic side (the easternmost part) changes its position from Greenland to the Norwegian Sea, and the Pacific side (the westernmost part) changes it from the Bering Sea to Alaska. In other words, both sides change their positions eastward.

Perlwitz and Graf (1995) showed a similar geographical pattern. They performed the canonical correlation analysis and the empirical orthogonal function analysis for the three winter months (December, January, and February) in order to investigate "barotropic" relation between the tropospheric and the stratospheric variation in geopotential height and temperature fields. Their first and second mode of 850hPa temperature (Figs 9 c and 10 c of their paper) are considered to correspond to the January and the February patterns of the present paper. This implies that the variance of lower tropospheric temperature field is statistically connected with the upper tropospheric persistent positive temperature anomaly of January and February.

These features suggest that some large scale atmospheric systems with the duration of at least one month may control the temperature fields. We can easily indicate two of such systems, the one is the Aleutian Low and the other is the Icelandic Low. These systems have the characteristics of standing waves in the northern hemispheric westerlies, so that they transport sensible heat poleward continuously for a long period. If these systems change those positions slightly, then they produce a drastic change in the temperature field (Umemoto, 1985). For example, Moses *et al.* (1987) showed the reversal positional relationship between the Icelandic Low and the Azores High from the viewpoint of the North Atlantic Oscillation.

Overland *et al.* (1996) showed three path ways of poleward heat flux across the latitudinal circle of 70N : the Greenland Sea, the Bering Strait, and the northern Canada. The former two are the main path ways and show relatively large interannual variability. They also indicated that about 50% of the total heat flux is brought by the transient eddies, and about 25% of it is due to the standing eddies. The transient and standing eddies of their analysis are considered to be including blocking activities and action centers respectively.

On the other hand, the North Pacific blocking made the large-scale positive (negative) surface temperature anomaly over the high (middle) latitudes in winter (Dole and Gordon, 1983 ; Umemoto, 1986). Blocking phenomena frequently occur even in the Arctic Basin in winter (e.g., Knox and Hay, 1985 ; Mullen, 1994). Colucci (1985) showed that blocking anticyclones has two kinds of the warming effect :

- the advective warming of winds,
- the adiabatic warming of the sinking air.

Therefore, the warm advection by the persistent blocking ridge or anticyclone can produce a warm-core event. Blocking phenomena take place especially in the North Atlantic, the North Pacific and the western Siberia. But the cut-off warm highs from blocking ridges do not always stay in the occurrence area.

The term *blocking* is originally derived from its effect to *block* the moving of synoptic or sub-synoptic scale disturbances. In many cases, a blocking flow pattern does not really block the cyclone passage, but fixes its tracks. This effect exerts an important influence upon the destruction of the strong surface temperature inversion.

Consequently the blocking phenomena in the Arctic have three kinds of contribution to produce warm-core events : 1) the warm air mass inside the blocking high and its subsidence, 2) the strong horizontal warm advection along persistent blocking ridges, and 3) the fixing of the cyclone track that breaks the surface temperature inversion.

In February, a queer phenomenon can be found in the northwestern part of Canada near the meridian of 120W. This area does not show a high value in surface chart (Fig. 4 d), but it shows about 40% in the upper levels (Figs 5 d and 6 d). A similar phenomenon can be seen over Mongolia in January. A relatively large area of high frequency (above 30% or more) is analyzed at upper levels. Both areas are situated in the inland region of the continents, and at the same time, in the core area of winter continental highs. The author, therefore considers that this phenomenon may be caused by the gradual formation of thick layer of temperature inversion.

On the other hand, we can see some areas with high frequency values over the oceans. These areas can be distinguished clearly in the upper levels. One marked high value area appears over the Atlantic Ocean off the coast of Europe in December, January, and March, but it appears over the Subtropics in February. If these areas have any substantial relations one another, it is noteworthy that these peaks change their position gradually from the north to the south. These positions are :

- November : the south of Greenland,
- December : the west of the northwestern Europe,
- January : the southwest of the West Europe,
- February : the west of Africa,
- March : the southwest of the West Europe again.

Over the East Pacific Ocean, the situation is almost the same as above :

- November : the west of Alaska,
- December : the south of the Aleutian Islands,
- January : the west of the USA,
- February : around California Peninsula,
- March : the west of the USA again.

This situation may be a statistical image of the magnitude of monthly mean temperature variance. The author thinks that this gradual displacement of the high temperature events reflects the seasonal sift of the action centers and the magnitude of cold outbreaks. This view may be supported by the fact that the position of the frequency peak returns from the south to the north in March, the end of winter.

5 Concluding remarks

The warm-core events of the Arctic winter appeared in the annual march of monthly mean air temperatures were detected by using the NMC octagonal grid data of the northern hemisphere from 1966 to 1987. The geographical distribution of the warm-core occurrence frequency was mapped for the surface, 700hPa, and 500hPa levels. The results of the analysis is summarized as follows ;

- Most cases of high temperature events (relatively warmer spells represented by monthly mean temperatures) appear in the middle and high latitudes of the northern hemisphere. The occurrence frequency is much higher in the high latitudes than the middle latitudes.
- In the Arctic, warm-core events occur intensively in January and February, but the distribution of occurrence frequency is different in each month. In January, the high frequency area is from the Bering Sea to Greenland through the Canadian Arctic. In February, it is from Alaska to the Norwegian Sea through Iceland.
- The above geographical features are in common among three levels of the troposphere (surface, 700hPa, and 500hPa).

The author proposes two causes of warm spells making warm-core events: 1) warm anticyclones cut off from blocking ridges that drift into the Arctic Basin, and 2) the large-scale warm advection in the northeastern side of the Icelandic and Aleutian lows.

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【要旨】

北極域の月平均気温変化に現れる冬季のウォームコア現象

梅　本　　亨

極地の冬は長いが，気温が低下し続けるわけではない。中緯度では真冬の一ヶ月を谷底とするV字型の気温変化グラフとなるが，極地では早い時期に気温が底を打ち，鍋底状のU字型となる。これをコアレスウィンターというが，その中に暖かい月が出現することがあり，ウォームコア現象と呼んでいる。北極圏では探検時代から気象学者に注目された現象だが，これまでに提出された成因には多くの難点がある。また，南極大陸にもウォームコアが出現するが，大陸氷床上の斜面滑降風による逆転層の破壊が主因である点で北極域とは異なる。本論では，北極域のウォームコアを，中緯度の大規模な寒波と対を為す現象として捉える。その発生原因は大気の作用中心とブロッキングリッジがもたらす総観規模の暖気移流であるとの仮説を立て，ウォームコアの出現頻度の地理的分布によってこれを検証する。

使用した気温データは，北極圏の対流圏全体で長期にわたり信頼のおける NMC（National Meteorological Center, USA）の北半球八角形グリッドデータである。冬季において前後の月より高温となった格子点を1965―66年から1986―87年の22冬について求め，その出現頻度を地上，700hPa 面，500hPa 面について月別に示した。その結果，ウォームコアは北極域の１月と２月によく発生するが，１月には北アメリカ大陸寄りに，また２月にはヨーロッパ寄りに，いずれもブロッキングが多発する領域を中心に分布する傾向が明らかである。この特徴は，各高度に共通するので，必然的に総観スケールで背が高く順圧的な構造をもつ暖気移流場の存在を示唆する。よって，ウォームコアの主因はブロッキングと作用中心の相互作用による暖気移流効果であると結論した。

なお，本論は人為的な温室効果ガスの放出によるいわゆる地球温暖化問題とは視点を異にすることを明記しておく。

キーワード：ウォームコア，コアレス・ウィンター，北極圏，ブロッキング，気温