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THE CHARACTERISTIC VARIATION OF T_b IN THE ANTARCTIC REGION REVEALED BY NOAA AVHRR CHANNEL-4 DATA

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Abstract: Based on the daily variation of T_b of NOAA AVHRR channel-4 data, several characteristic features of the variation of T_b in the Antarctic region were presented. Remarkable differences in the T_b variation between ocean and continent were found.

The amplitude of the seasonal cycle of the T_b variation is much larger over the continent than the ocean, because of the strong inversion over the continent in winter.

The short term T_b variation within 10 days over the ocean is controlled by synoptic disturbances. The T_b variation over the continent revealed longer periodicity of a few tens of days. The variation is caused by the cloud intrusion into the Antarctic continent.

1. Introduction

Satellite data can provide us much information on the atmosphere and cryosphere in the polar regions where direct field observation is difficult. NOAA AVHRR data is a very powerful tool for this study since it has sufficient resolution in space and time. Recently, the cloud variation in polar regions has draw attention from the viewpoint of cloud climatology. YAMANOUCHI *et al.* (1987) investigated the method of detection of clouds over the cryosphere by the use of multi-channel data. The detection of clouds in the polar region remains a difficult problem for climate research.

In this paper, channel-4 (ch-4; infrared, 10.3–11.3 μm) of NOAA AVHRR data is used and the variation of T_b (brightness temperature) on daily to annual time scales is investigated. The T_b variation is described and interpreted. Even a brief sketch of the T_b variation obtained from a single channel can be useful in the Antarctic region where upper-air soundings are sparse.

2. Data

NOAA AVHRR data have been received and analyzed at Syowa Station, Antarctica. Observations were made once a day from February 1988 to January 1989 under the Antarctic Climate Research (ACR) project. By a real time processing system (TAKABE and YAMANOUCHI, 1989), the received data have been converted into

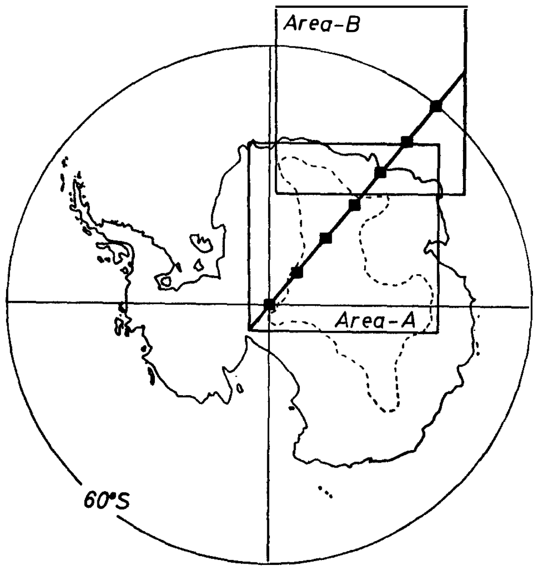

Fig. 1. Observed areas and analyzed section along 39°35′E (heavy line). Squares on the line show every 5 degrees of latitude from 60°S to 90°S. Contour of 3000 m altitude is by broken line.

mesh data with resolution of 4.4 km at nadir. The areas in which the data have been compiled are shown in Fig. 1.

Compiled AVHRR T_b data on ch-4 were used in this study. Data were received from February 1988 to September 1988 from NOAA-9, and from NOAA-11 after October 1988. There are 17 days' missing data out of 366 days; no gap of the data is longer than 2 days except from 6 to 10 January, 1989. Gaps were filled by interpolation. The observation time was about 17 LT and 15 LT in the case of NOAA-9 and NOAA-11, respectively. The diurnal cycle of short wave radiation largely affects the variation of T_b on clear summer days. No correction was applied for this problem. The results of this paper, however, are almost unaffected by this problem.

3. Characteristic Features of T_b Variation

Selected data along 39°35′E (heavy line in Fig. 1) are mainly analyzed in this section. The receiving station (Syowa Station) is located on this line and the widest area in latitude can be obtained with good quality along this line.

Figure 2 shows time sequence of daily variation of T_b every 5 degrees of latitude on 39°35′E (each point is shown as a square in Fig. 1). The value at each latitude was calculated as an average of 9×9 pixels of mesh data (*i.e.* about 40 km$\times$40 km). 70°S is located just at the coast between the Antarctic continent and the Southern Ocean. The points from 75°S to 85°S are located on the inland plateau above 3000 m.

To clarify the seasonal cycle of the T_b variation, the variations of the monthly average of T_b at 60°S, 70°S and 80°S are shown in Fig. 3. Standard deviations at 60°S and 80°S are shown in Fig. 4. To see the standard deviation in each month, the seasonal cycle was eliminated by a high pass filter (SAITO and ISHII, 1969).

Apparent characteristic of the T_b variation are as follows.

1) Annual range of the variation is greater in the continental region (the amplitude is about 50 K at 80°S) than that in the oceanic region (less than 15 K at 60°S). In November and December, T_b at 70°S reveals higher values than at 60°S.

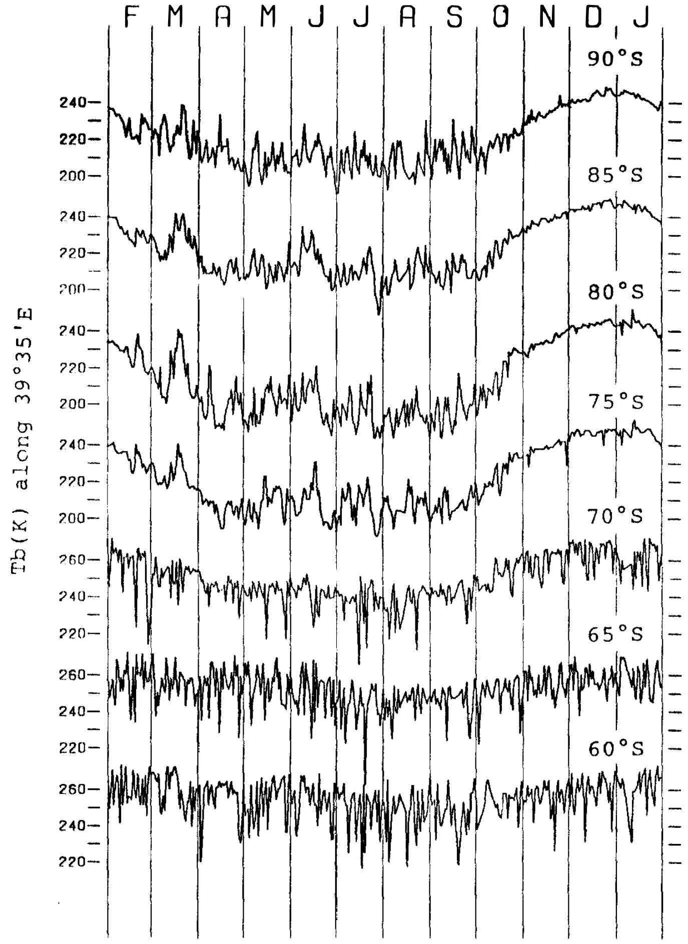

Fig. 2. Time sequences of daily variations of T_b every 5 degrees of latitude from 60°S to 90°S along 39°35′E. The data are from Feb. 1, 1988 to Jan. 31, 1989.

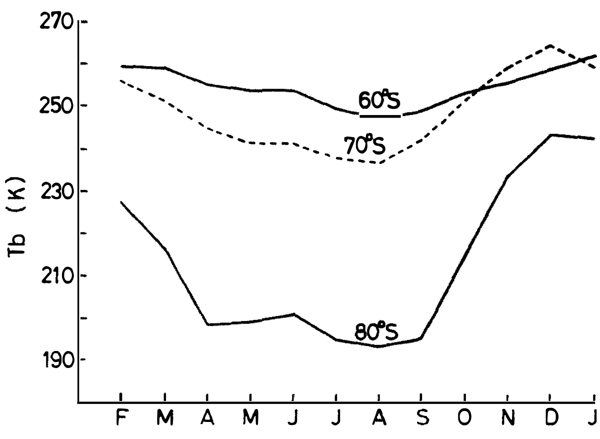

Fig. 3. Seasonal cycles of the monthly mean T_b at 60°S, 70°S and 80°S.

2) In the continental region (south of 70°S), there is remarkable variation with large amplitude (about 30 K) and a few tens of days. The large variation can be found especially from March to September, while there is very little variation after November.

3) In the oceanic region (north of 70°S), short-term variation dominate throughout the year. The monthly standard deviation reveals no apparent seasonal dependence,

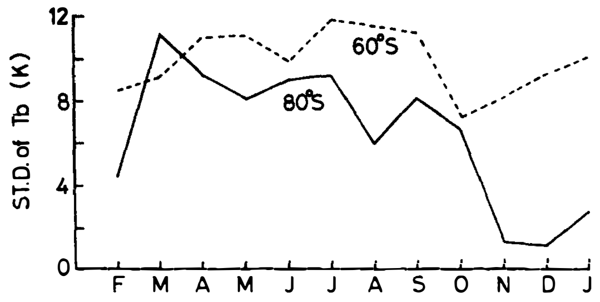

Fig. 4. Seasonal cycles of the standard deviation of the T_b variation in each month at 60°S and 80°S.

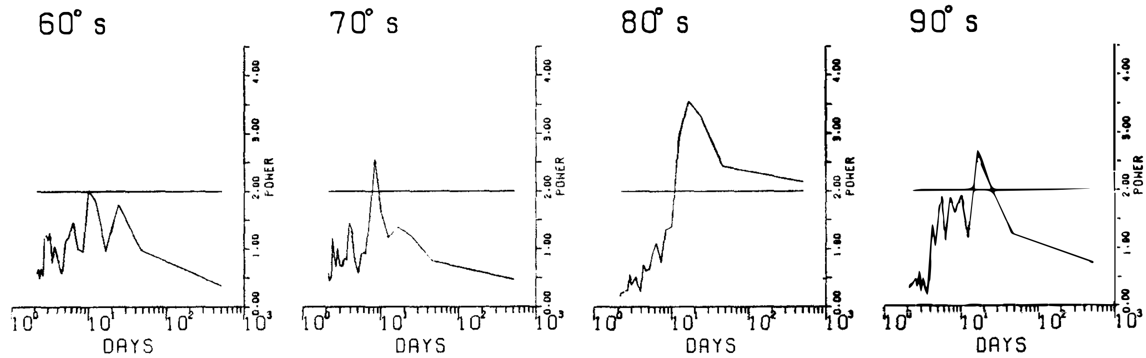

Fig. 5. Power spectra of T_b variations every 10 degrees of latitude. Ninety-nine percent confidence level is shown by a horizontal line.

while a slight decrease can be noticed in summer months.

4) In the coastal region (70°S), several spiky variations, which mean abrupt decrease and increase of T_b within a few days, can be seen intermittently.

To calculate the dominant period of variations other than the annual cycle, Fast Fourier Transformation (FFT) was applied to the time series after eliminating variations longer than 100 days by a high pass filter. Figure 5 shows the power spectrum of the Tb variation at each latitude. There is no significant periodicity at 60°S. The dominant variation component is about 9 days at 70°S. Strong power can be seen from 15 to 40 days at 80°S and 90°S. Short-term periodicity less than 10 days reappears at 90°S. It is clear that a remarkable difference of periodicity exists between ocean (north of 70°S) and continent (south of 70°S). Apparent periodicity longer than 10 days appears only in the variation in the continental region especially at 80°S (the highest point of the analyzed points).

To clarify the spatial pattern of the variation, Empirical Orthogonal Function (EOF) analysis was performed. Sixty-four points were selected along 39°35′E at uniform intervals and a correlation matrix among these data was calculated. The seasonal cycle was eliminated by a high pass filter before taking the correlation. Figure 6a shows the spatial patterns of the first three components obtained by EOF analyses. The time series of each component is shown in Fig. 6b. The 1st component whose variance is 29.2% of the total variance shows large amplitude over the continent. The large variation before October contrasts to the almost no variation after November. The large variation seems to have a periodicity longer than 10 days. In the 2nd component, a large amplitude appeared in the oceanic region and the variation has shorter

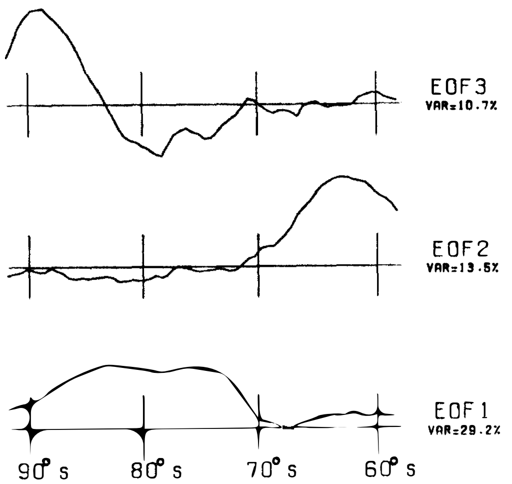

Fig. 6a. Spatial structures of the first three dominant components revealed by EOF analyses.

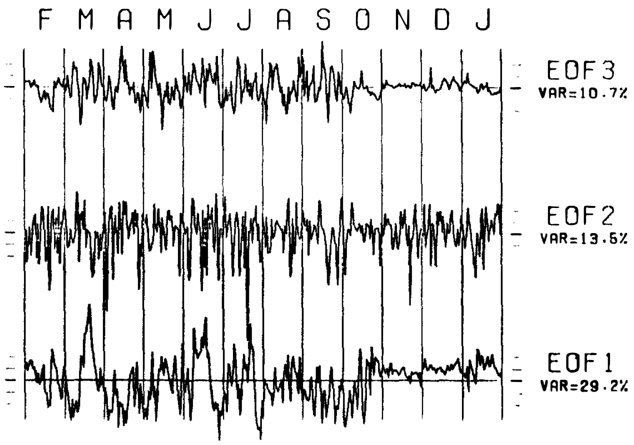

Fig. 6b. Time variations of the first three dominant components shown in Fig. 6a.

periodicity than the 1st component. The 3rd component shows dominant variation around the South Pole. This variation may represent the effect from the West Antarctic region. The first two components clearly show the characteristic differences of the T_b variations between continent and ocean which we have noticed in Fig. 2.

4. The Cause of the T_b Variation

The T_b variations found in the previous section include information of both surface temperature and clouds. We will present possible causes of the variations.

a) Seasonal cycle

The latitudinal dependence of the annual range of the T_b variation (Fig. 3) is similar to that of the surface air temperatures at Antarctic stations (VAN LOON, 1967). The variation over the continent shows typical variation of the coreless winter type. It can be said that the seasonal cycle of T_b over the continent is primarily determined by the strong inversion over the interior of the Antarctic continent (SCHWERDTFEGER, 1984).

In the oceanic region, the average T_b was about 250 K at 60°S and 65°S. The development of sea ice and active cloud both reduce the T_b below 270 K, which is that of the unfrozen sea surface. The colder T_b at 60°S than 70°S in December is considered to be due to clouds, because there is no sea ice at 60°S in summer.

b) Variation of T_b over the ocean

The short-term T_b fluctuation with large amplitude is considered to be due to the variation of clouds. The small seasonal dependence of the variation (Fig. 4) suggests continuous cloud activity. However, we cannot tell exactly how far the clouds extend by using only T_b, especially in winter, because the surface temperature on sea ice is close to the T_b of clouds. T_b on land-fast sea ice in Lützow-Holm Bay (about 70°S) can be as cold as 240 K in mid-winter. The surface temperature on pack ice in lower latitudes is considered to be higher than this value. It is fair to say that at least T_b colder than 240 K can be regarded as clouds over the winter pack ice zone. Cyclonic storms are often associated with active clouds whose T_b is less than 220 K, which appear a few times each month. The most practical way of separation is pattern recognition of pack ice structure. High amount of clouds in the winter Southern Ocean can be suggested from the observational fact that we can observe the pack ice structure only a few days in a whole winter.

c) Variation of T_b in coastal region

Figure 7 shows the variation of T_b at 70°S and southward moisture flux which is calculated from the upper air sounding data at Syowa Station. Moisture flux is used as an index to show the approach of cyclonic disturbances. Large southward moisture flux corresponds to the spiky decrease of T_b at 70°S. The variation is caused by clouds which develop when an active disturbance approaches the coast.

Clearer correspondence between the variations of T_b and moisture flux can be seen at 900 mb than at 600 mb. Even in weak disturbances confined to the lower

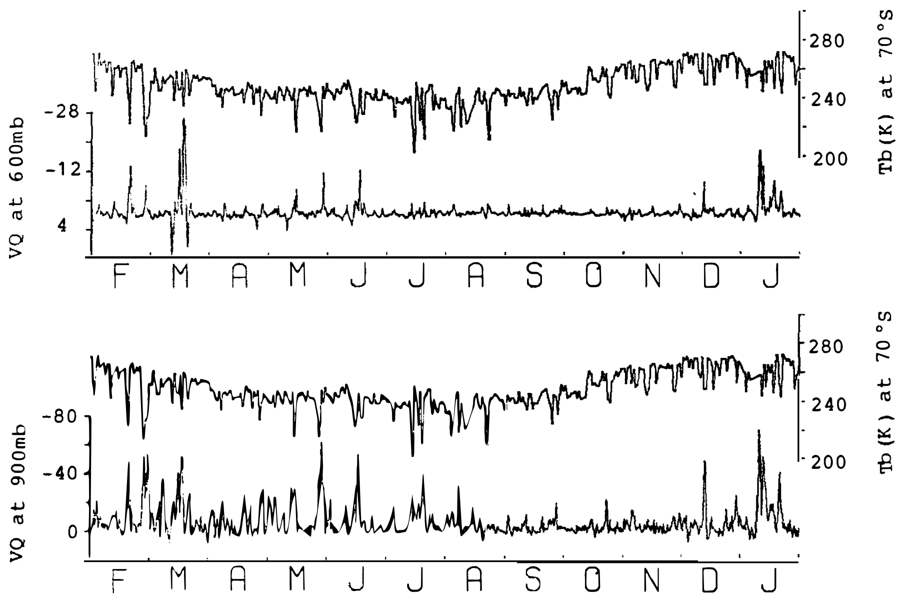

Fig. 7. Time sequences of southward moisture flux (VQ) at 900 mb and 600 mb level at Syowa Station and T_b at 70°S. Unit of VQ is g/(m s).

troposphere, clouds can be formed on the ice slope by forced upward airflow and affect the variation of T_b. The variation of T_b became active in the later part of the year due to low clouds, while the numbers of disturbances which approached to the coast was small.

d) Variation of T_b over the continent

Figure 8 shows the variation of daily images of T_b in July, 1988 in the continental region (Area-A in Fig. 1). In early and late July, T_b is generally low and the contour of T_b has a similar shape to the altitude contour on the ice sheet (Fig. 1). In middle of the month, in contrast, high T_b appears. They change their shapes day by day and some of them has a vortex shape. In winter, generally, the surface temperature in the interior of continent becomes less than 200 K due to the strong inversion (SCHWERDTFEGER, 1984), while the temperature in the middle troposphere is several tens of degrees

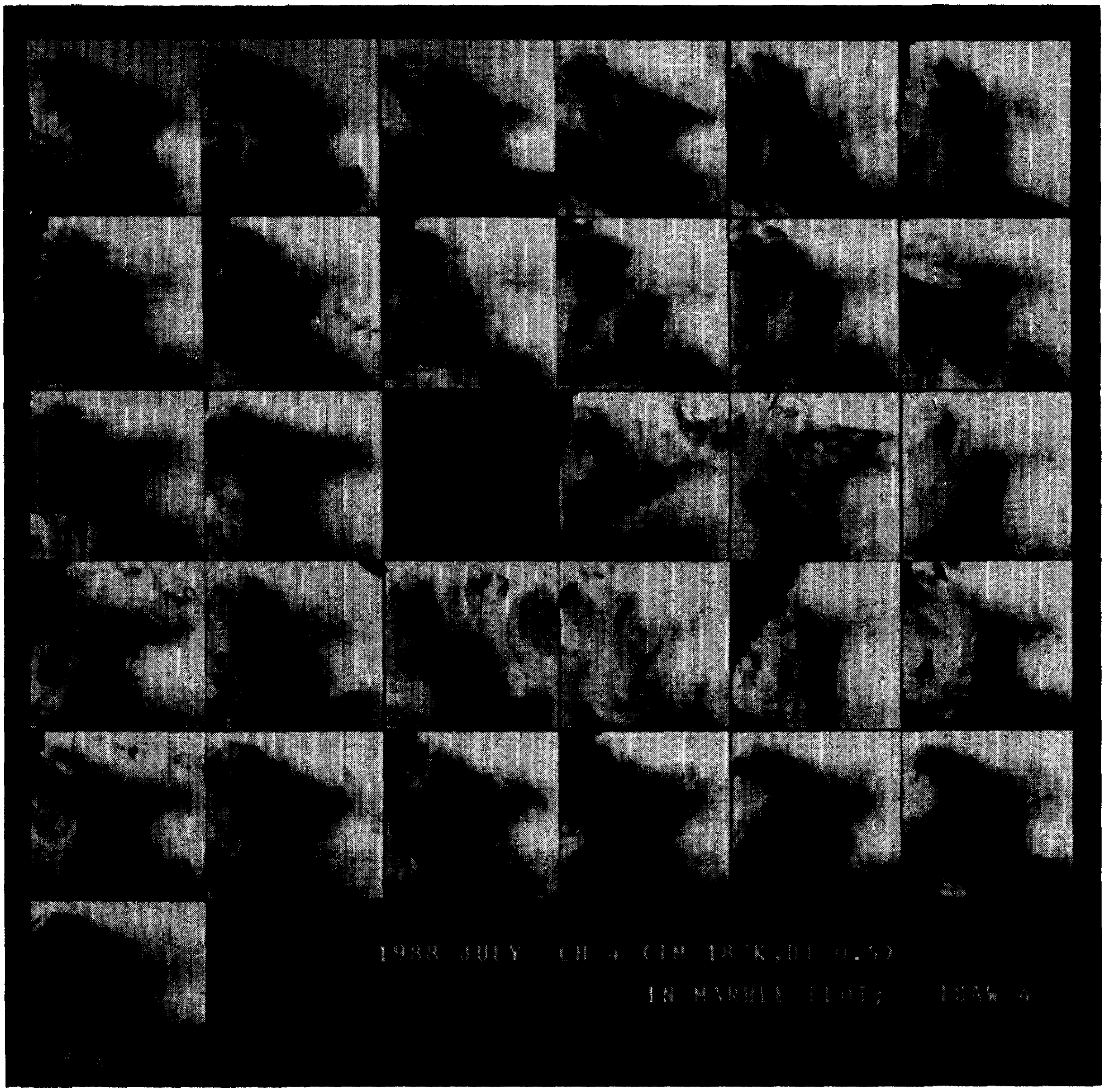

Fig. 8. Daily images of T_b in Area-A in July 1988. White and black color mean high and low T_b respectively.

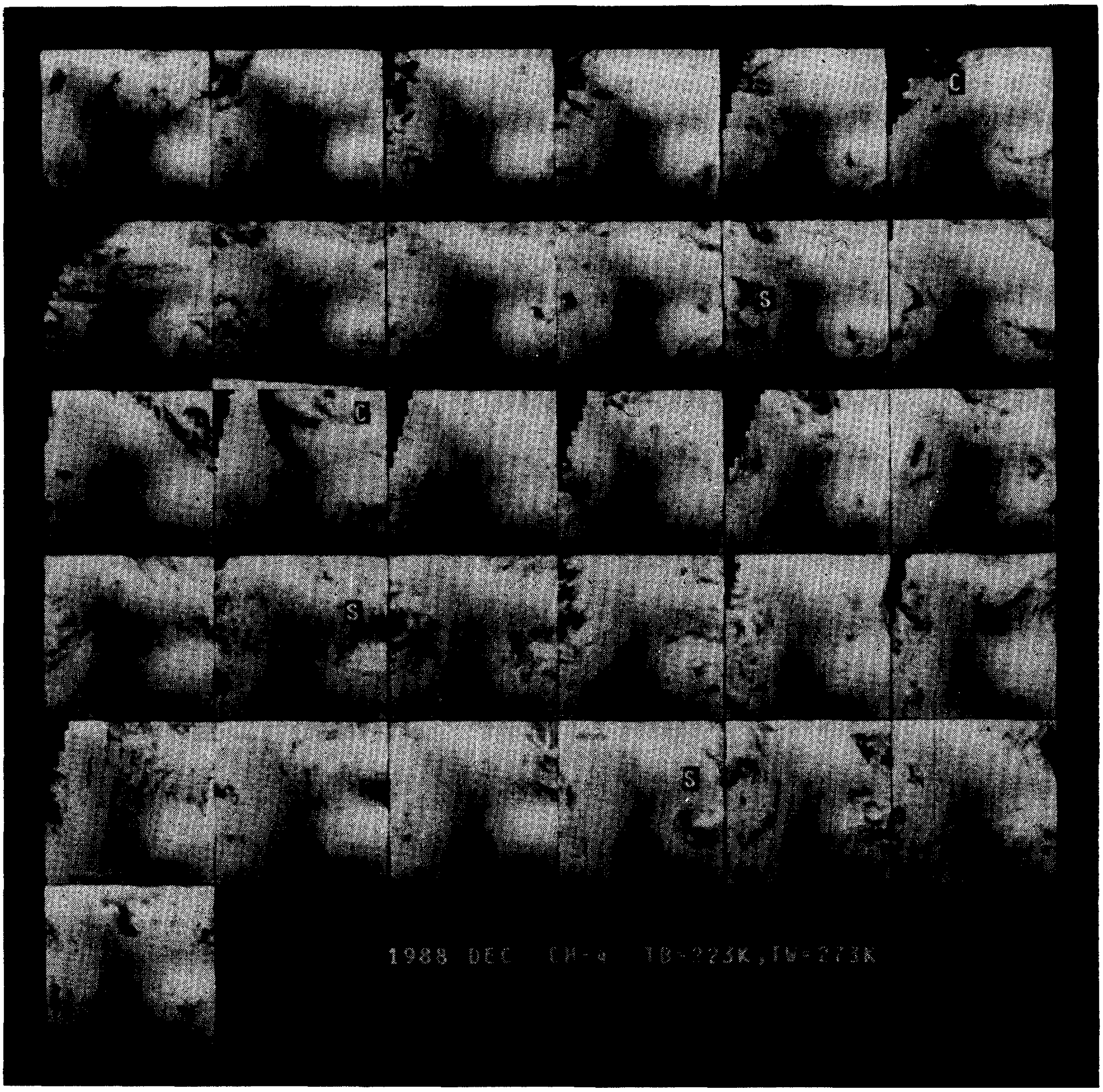

Fig. 9. Same as Fig. 8 except in December.

higher than the surface temperature. Hence, an increase of T_b can be seen if there are some clouds over the continent. It is concluded that the high T_b (above 220 K) in the winter continental region in Fig. 2 mainly corresponds to the intrusion of clouds over the continent.

Figure 9 shows daily images in December 1988. In summer, the T_b of clouds is generally colder than that of the ice surface, while the difference remains small. Intrusions of typical cloud bands associated with cyclonic disturbances (C in the figure) are rare, while stratus clouds (S) can be observed frequently in the coastal region. The small T_b fluctuation in summer is a result of the weak T_b contrast and the decrease of the number of disturbances.

Finally, we investigate the relationship between the T_b variation with periods of more than a few tens of days and atmospheric circulation. The T_b variations at 80°S are compared with the variations of temperature (Fig. 10a) and geopotential height

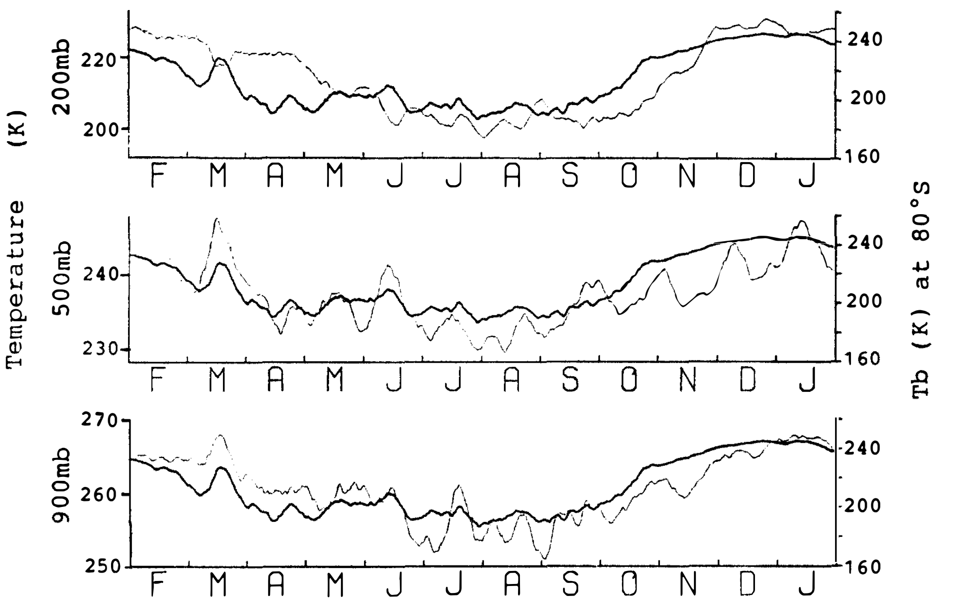

Fig. 10a. The variation of T_b at 80°S (thick line) and the temperatures (T) at 3 levels over Syowa Station (thin lines) from Feb. 1988 to Jan. 1989.

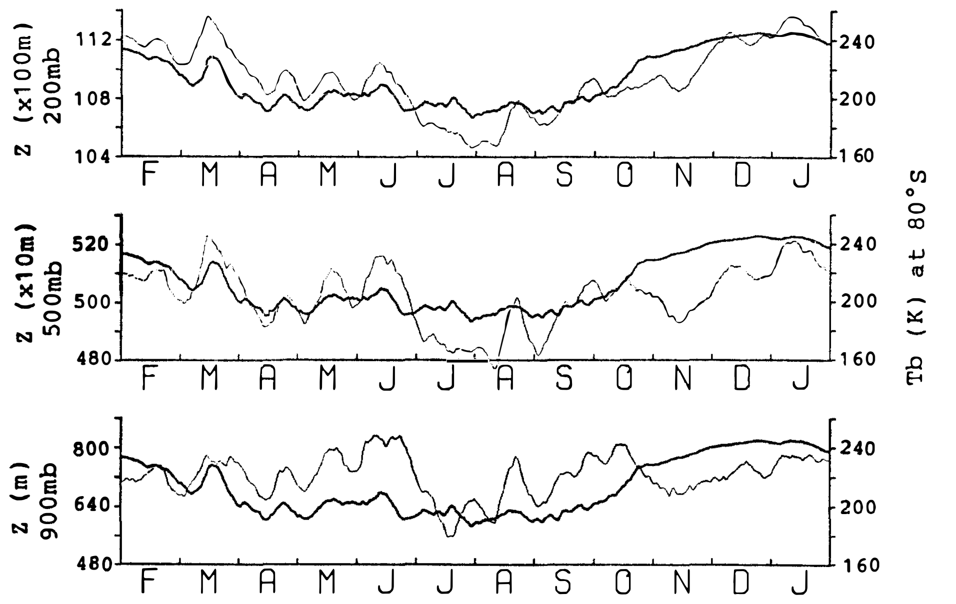

Fig. 10b. Same as Fig. 10a except geopotential heights (Z).

(Fig. 10b) at Syowa Station. A ten day's running-mean filter was applied to both data sets to focus on low frequency variations. Although the time sections were taken at different locations, in-phase variation of the temperature with T_b can be seen at 500 mb before September. The correspondence becomes unclear at 200 mb and 900 mb, and after October. The in-phase variation of geopotential height can be seen through the troposphere (900 mb and 500 mb) and stratosphere (200 mb) before June. High T_b (intrusion of cloud) into the continental region corresponds well to high temperature in mid-troposphere and high geopotential height at Syowa Station early in the year.

5. Discussion

The short-term variation of T_b in the oceanic region is mainly due to the variation of cyclonic disturbances. The continuous active variation throughout the year suggests never-ending cyclonic activity in the Southern Ocean. Some of them approach the coastal region occasionally with a period of about 10 days. Clouds intruded into the interior of the continent with the periodicity of a few tens of days in winter, and rarely in summer. The difference of periodicity suggests that some mechanism controls this variation.

The existence of an anticyclonic circulation over the continent (*i.e.* Antarctic anticyclone) in winter has been confirmed by analyses of upper air soundings (RUBIN and WAYANT, 1963; NAKAMURA and OORT, 1988), while a large quantitative discrepancy exists among values obtained from different data sets (MASUDA, 1990). Due to very sparse upper-air soundings, it is difficult to obtain a comprehensive picture of the variation of the Antarctic anticyclone. The observation of clouds from a satellite is a simple but powerful way to detect the variation of the anticyclone because a cloud is a visible signal of vertical air motion in the troposphere.

The cloud variation over the Antarctic continent may suggest the fluctuation of the strength or position of the Antarctic anticyclone. Adiabatic warming due to descending motion in the anticyclone may be smaller than the radiative cooling of the middle troposphere over the winter continent. This situation can increase baloclinicity surrounding the Antarctic continent and disturbances often intrude. The more active cloud intrusion in winter than in summer is consistent with the large snow accumulation in winter at Vostok and South Pole stations (BROMWICH, 1988) and the intermittent intrusion of warm air observed at Plateau station (KUHN *et al.*, 1973).

The variation of clouds over the winter Antarctic continent has a marked periodicity of a few tens of days. There are some studies which mention the variability of meteorological fields around Antarctica with the period of a few tens of days. YASUNARI (1981) analyzed the variation of temperature in mid-troposphere at Syowa Station and reported the existence of a few tens of days variability in several years' data. KAKEGAWA *et al.* (1986) found similar variation in the surface pressure at Mizuho Station, Antarctica and the intensity of the polar anticyclone in ECMWF data. YODEN *et al.* (1987) investigated the zonal mean wind field in the Southern Hemisphere and found a characteristic variation of similar period. They mentioned the seasonal increase of these variations in winter and the relationship between the variability of the planetary wave amplitude of wave number 1 or 3 and their findings.

We cannot tell the spatial structure of the cloud variation on the Hemispheric scale. However, the cloud variation is also controlled by the variability of planetary waves because the storm track is greatly influenced by the variation of the planetary waves (YASUNARI, 1977). Some correspondence of high geopotential height at Syowa Station and the active intrusion of clouds (Fig. 10b) may suggest the fluctuation of the Antarctic anticyclone mentioned by KAKEGAWA *et al.* (1987).

ENOMOTO (1991) analyzed the relationship between the sea level pressure around Antarctica and snow accumulation on the Antarctic ice sheet which is derived from glaciological data. He showed the existence of a variation with period of several decades and the existence of zonal and non-zonal (wave number 1) structures of the variations. It is interesting to investigate whether the spatial patterns in the variations of hydrological elements with different time scales are the same or not.

There has been few analyses of hydrological elements in the atmospheric circulation around Antarctica in inter-annual or inter-decadal time scale. The variation of clouds must be related to the variation of accumulation on the ice sheet. Further climatological study of hydrological elements in the polar region is necessary.

6. Conclusion

Based on the daily variation of T_b of NOAA AVHRR channel-4 data, several characteristic features of the T_b variation in the Antarctic region were presented. There were remarkable differences in the T_b variation over the ocean and continent.

One of them is found in the amplitude of seasonal cycle. T_b over the continent revealed a large seasonal cycle. The strong inversion over the Antarctic continent in winter is the primary cause of the large amplitude.

Another difference can be seen in the fluctuation with shorter period. The dominant period of the variation over the continent was a few tens of days, while it was less than 10 days in the oceanic and coastal regions. The variation over the continent was much larger in winter than in summer, while the variation had no apparent seasonal dependence in the oceanic region.

The short-term variation in the oceanic region is due to the continuous activity of cyclonic disturbances. The fluctuation over the continent was due to the intrusion of clouds into the interior. The variation of T_b in the continental region partly corresponds to the variation of temperature and geopotential height at Syowa Station. It is possible to say that the variation of clouds over the continent with period of a few tens of days is linked to the variation of the Antarctic anticyclone.

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