Geographical Review of Japan
Vol. 62 (Ser. B), No. 2, 161 – 169, 1990

Large-Scale Atmospheric Circulation Patterns Associated with the Cold Surges in Yunnan Province, China

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Abstract

The dominant time-space structure of cold surges affecting Yunnan Province and the whole of China are investigated by applying an empirical orthogonal function (EOF) analysis of monthly surface temperature anomalies for the winters of 28 years (1959 – 1986). It has been revealed that the predominant mode for Yunnan Province is part of the cold surge over the eastern periphery of the Tibetan Plateau through the coastal area of the southernmost part of China. The predominant mode for the whole of China affects most parts of China particularly to the south of 40°N centered near the Yangtze River basin, but its influence upon Yunnan Province is small. The atmospheric circulation patterns associated with these two modes are deduced by producing composite charts of 500 mb height and sea level pressure anomalies in the Northern Hemisphere. The pattern for the dominant mode of Yunnan Province shows the so-called Eurasian pattern with the anomalous trough over central Asia, and the North Atlantic Oscillation with negative polarity over Greenland. The pattern for the dominant mode over the whole of China seems, in contrast, to be more directly related to the outbreak of a cold air mass over the eastern part of the continent.

Key words: cold surges, Yunnan Province, atmospheric circulation.

I. INTRODUCTION

Yunnan Province is located in the southernmost part of the mainland of the People's Republic of China (P.R.C.). Most of the province is occupied by a mountainous plateau with an altitude of 1,500 m or higher, called the Yun-Gui Plateau. This plateau takes the form of the lower part of the Tibetan Plateau extending southeastward to the lower latitudes. The climates of this area have, therefore, a wide range from a tropical climate in the southern lower part to a polar climate in the northwestern higher part near Tibet. This area is also strongly influenced by the summer and winter monsoons, which further produce seasonal as well as spatial varieties of local climates under the complex mountainous terrain.

Most of the province at altitudes lower than 2,000 m is dominated by a subtropical climate, where the monthly mean temperature in winter generally does not go down below 8°C even in the coldest month (YOSHINO, 1989). However, this province is sometimes affected by a cold air mass from the North Polar region or the interior of the Eurasian continent. For example, at the end of December of 1983, a severe cold surge hit the northern part of this province, providing heavy snowfall and a great fall in temperature for several days. In Kunming (1,890 m a.s.l.), the capital of the province, the temperature fell to − 3°C and the maximum snow depth reached 36 cm.

Synoptic weather conditions of cold waves or surges in this region have been reported and discussed by some meteorologists and local forecasters (e.g., MO, 1983; GAO and QIAN, 1984; DUAN and ZHANG, 1987). However, the large-scale and the long-term aspects of cold waves in this region, such as the dominant spatial structures associated with large-scale orography, and the hemispheric features of the atmospheric circulations responsible for the cold surges, still remain unresolved. These problems may also be important for the long-range forecasting of cold

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surges in this region.

This short paper attempts preliminarily to deduce the time-space characteristics of the monthly mean temperature anomaly during winter as an indicator of cold (or warm) waves over Yunnan Province as well as the whole of P.R.C. and to discuss their association with the anomalous circulation field of the Northern Hemisphere.

II. DATA AND METHOD OF ANALYSIS

Monthly mean surface temperature data for the winter months (December, January, and February) of 32 stations in Yunnan Province and 160 stations in the whole of the P.R.C. for 28 years (1959 – 1986) comprise the main data set for this study. Monthly mean gridded (10° × 10° longitude/latitude) data of sea level pressure (SLP) and 500 mb geopotential height compiled by the Japan Meteorological Agency are used to examine the atmospheric circulation field.

To deduce the dominant spatial patterns of temperature anomalies over the provincial scale as well as the whole of the state scale, an empirical orthogonal function (EOF) analysis is applied separately to the two temperature data sets mentioned above. The temperature anomalies are produced by subtracting the 28-year mean monthly value from the original temperature values of each month, and these anomalies for all the winter months (i.e., 84 months for each station) are subjected to the EOF analysis. A correlation matrix is adopted to obtain the EOFs, to normalize the differences in the actual temperature variances between the stations, which largely depend upon geographical and topographical conditions.

The anomalous circulation patterns associated with the typical colder (or warmer) months, which are derived from the coefficients of a time series of the dominant EOFs, are then deduced by producing composite charts of SLP and 500 mb height anomalies. The results for the province scale and for the whole-of-China scale are compared in order to understand the nature of the interannual variability of cold waves in this southernmost part of China.

III. PRINCIPAL MODES OF TEMPERATURE ANOMALIES FOR YUNNAN PROVINCE AND FOR THE WHOLE OF CHINA

Fig. 1 shows the first two EOF patterns for Yunnan Province and their time coefficients. The eigenvalues and the variance of the first five EOFs are shown in Table 1. Since the third and the other minor EOFs occupy a far smaller portion of the total variance (Table 1) and their spatial patterns show more or less complex and localized patterns compared to the first two EOFs (not shown), discussions will be made only for the first two modes. The first EOF shares about 60% of the total variance, which represents the major temperature fluctuation over the whole province. Only in the most southwest part of the province near the border of Myammar, the contribution of this mode is small compared to the other part of the province. The mountainous northwest region near the Tibetan Plateau is, in contrast, a center part of this mode. Most of the severely cold months associated with the abnormally strong cold surges (e.g., December 1983) seem to be explained by this mode as shown in the large negative time coefficients.

The second mode (17% of the total variance) is far less representative compared with the first

Table 1 Eigenvalues, variances and cumulative variances of the first 5 components of the EOFs of temperature anomalies in Yunnan Province

COMP No.	Eigenvalue	Variance (%)	Cumulative Variance (%)
1	19.2	59.9	59.9
2	5.3	16.7	76.6
3	2.4	7.5	84.1
4	1.2	3.7	87.8
5	0.8	2.4	90.2

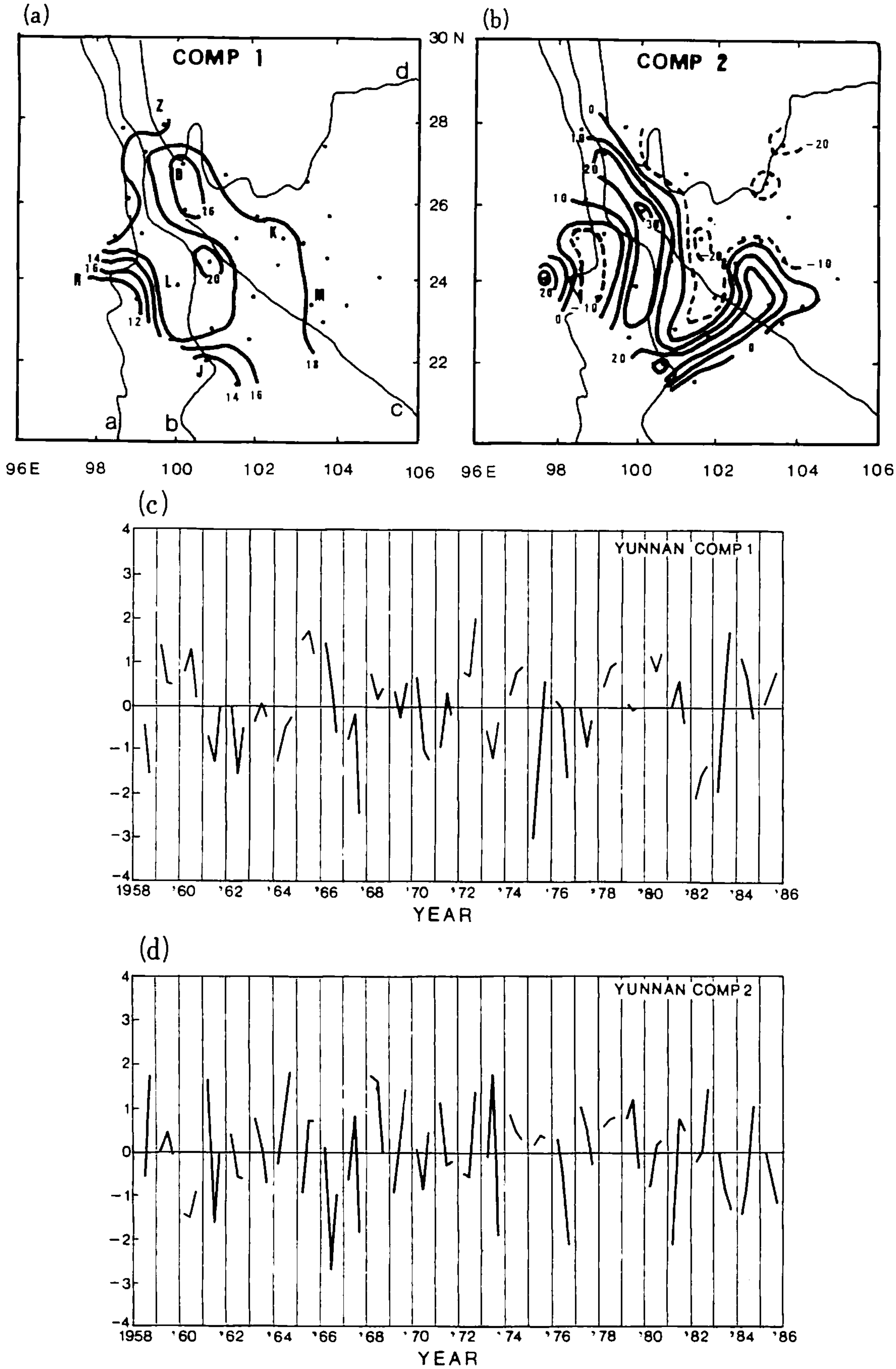
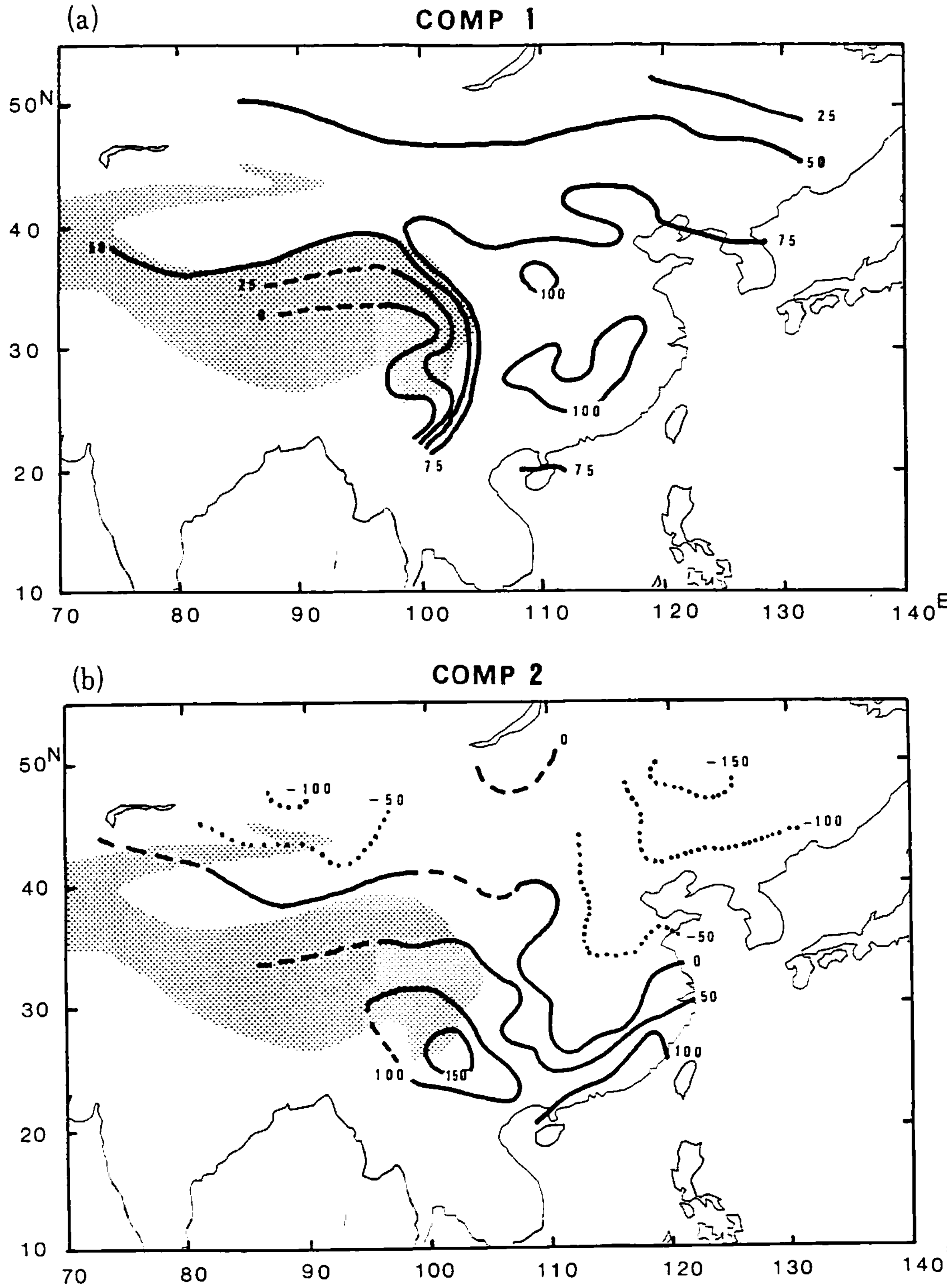


Figure 1. Eigenvector Patterns and Time Coefficients for Yunnan Province

Eigenvector patterns of (a) the 1st and (b) the 2nd component of the EOFs and the time coefficients of (c) the 1st and (d) the 2nd component for Yunnan Province. Distributions of stations used for the EOFs are shown in (a) and (b). Units in (a) and (b) are multiplied by 10. Initials of some stations are shown in (a) as follows: Z: Zhongdian, R: Ruili, D: Dali, K: Kunming, M: Mengzi, L: Lincang, J: Jinghong. Four major rivers in the province are also shown as follows: a: Nu Jiang (River), b: Lancang Jiang, c: Yuan Jiang, d: Jinsha Jiang.

mode, but its spatial pattern (Fig. 1(b)) is very interesting in view of the orographic effect on the cold surges. This pattern approximately represents the contrast in the temperature anomaly between the northeast and the southwest part of the province, but the large positive eigenvectors seem to distribute along the Lancang (Mekong) River basin and the mountains near the Vietnam border. That is, this pattern suggests two types of cold surges: one affects only the northeast part of the Yungui Plateau, the other is confined along the major river from the Tibetan Plateau (e.g., the Lancang River) and the mountain side along the southern border.

In order to examine the association of these two dominant modes for the province scale with



those of the whole-of-China scale, the same EOF analysis was applied to the 160 stations in the whole of China, including 10 stations in Yunnan Province. Fig. 2 shows the spatial patterns for the first two EOFs. The first component (which explains 56.3% of the total variance) represents the simultaneous temperature fluctuation over the whole of China centered to the south of the Yangtze River basin. However, this mode seems not to explain the major portion of anomalies in Yunnan Province.

The second component (11.4% of the total variance) is a minor mode compared to the first component, which represents an oscillation of temperature anomaly between northeast China and the southernmost part of China. It should be noted, however, that a southern center of action of this mode is exactly located in Yunnan Province and the series of time coefficients is highly correlated to that of the first component for the province-scale (Fig. 2(d)). In fact, the correlation coefficient between these two series is proved to be 0.72, which far exceeds the 0.1% significant level. Interestingly, the first compo-

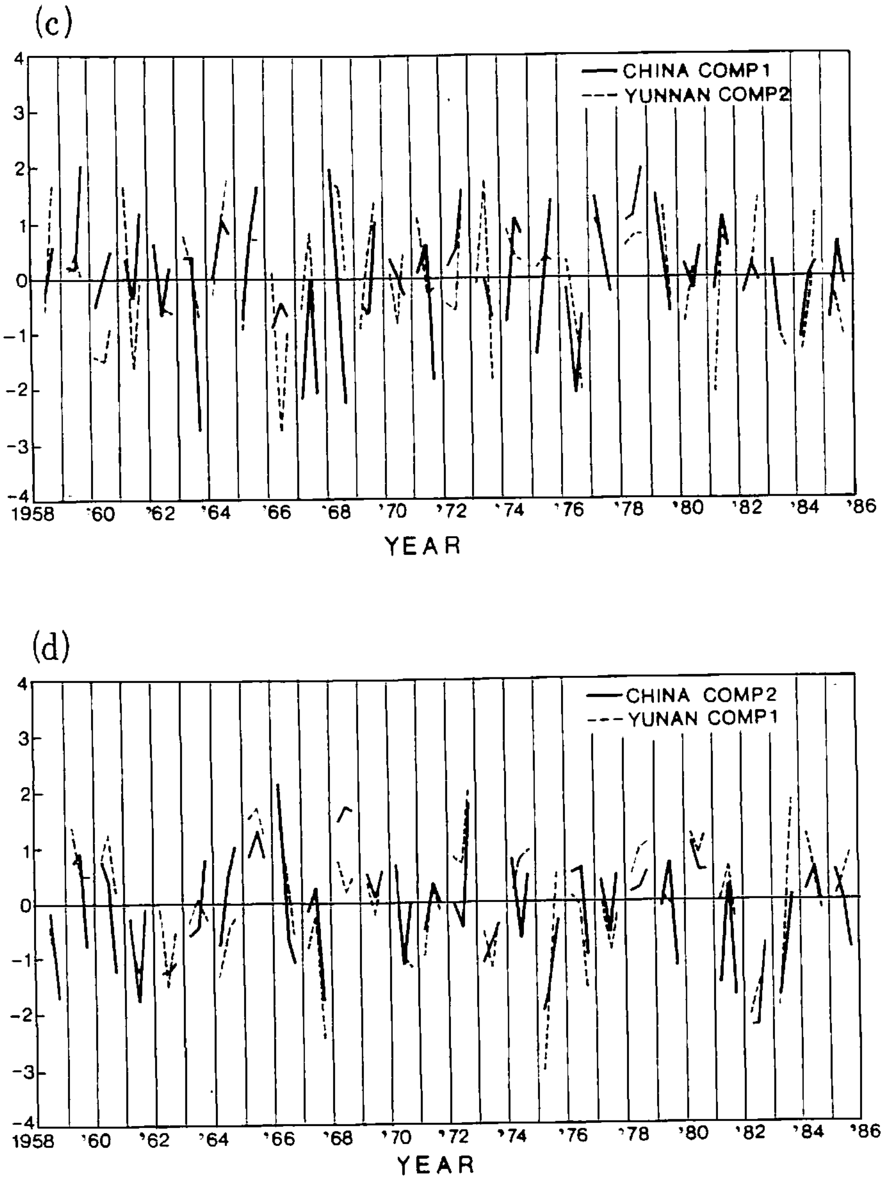


Figure 2. Eigenvector Patterns and Time Coefficients for the Whole of China

Same as Fig. 1 but for the whole of China. Hatched areas in (a) and (b) indicate the Tibetan Plateau higher than 3,000 m. Units in (a) and (b) and multiplied by 10. Dashed lines in (c) and (d) denote the coefficients of the 2nd and the 1st component for Yunnan Province, respectively.

nent for the whole of China seems to correspond to the second component for Yunnan Province, as shown in Fig. 2(c). These results suggest that the cold waves predominantly affecting the most part of the broad plain area only marginally affect Yunnan Province, but those dominantly affecting the whole province are actually part of larger-scale cold waves affecting areas over and around the Tibetan Plateau and the southernmost part of China. Here we simply call the former the Plain mode, and the latter the Yunnan mode.

IV. ATMOSPHERIC CIRCULATION OF ANOMALIES ASSOCIATED WITH THE PLAIN MODE AND THE YUNNAN MODE

The atmospheric circulation anomalies associated with the cold (or warm) phases of the Plain mode and the Yunnan mode are deduced here, by compositing the 500 mb height and SLP anomalies of the corresponding months over the Northern Hemisphere North of 30°N. The months of cold (or warm) waves are selected based on the negative (or positive) time coefficient values exceeding the unit (standard deviation) values.

Fig. 3 shows the composite 500 mb height anomaly chart of the Northern Hemisphere for cold months of (a) the Yunnan mode and (b) the Plain mode. A remarkably different pattern is apparent between the two maps, particularly over the Eurasian continent, where in the Yunnan mode an anomalous trough extending from the north polar region is apparent over central Asia but in the Plain mode a zonally-oriented positive anomaly is dominant through the northern part of the continent. Another distinct feature in the Yunnan mode is a core of large negative anomalies over the North American polar region near Greenland, where the significant level of the anomalies in the t-test uniquely exceeds 5%, except for the southern part of China. In fact, the negative anomalies over central Asia and those over the Greenland area seem to form a large area of negative anomalies. The composite charts for the warmer months of these modes show nearly the same pattern but with reversed signs particularly over the Eurasian continent through the North Atlantic region (not shown). The anomaly pattern of the Yunnan mode over Eurasia (Fig. 3(a)) can be identified

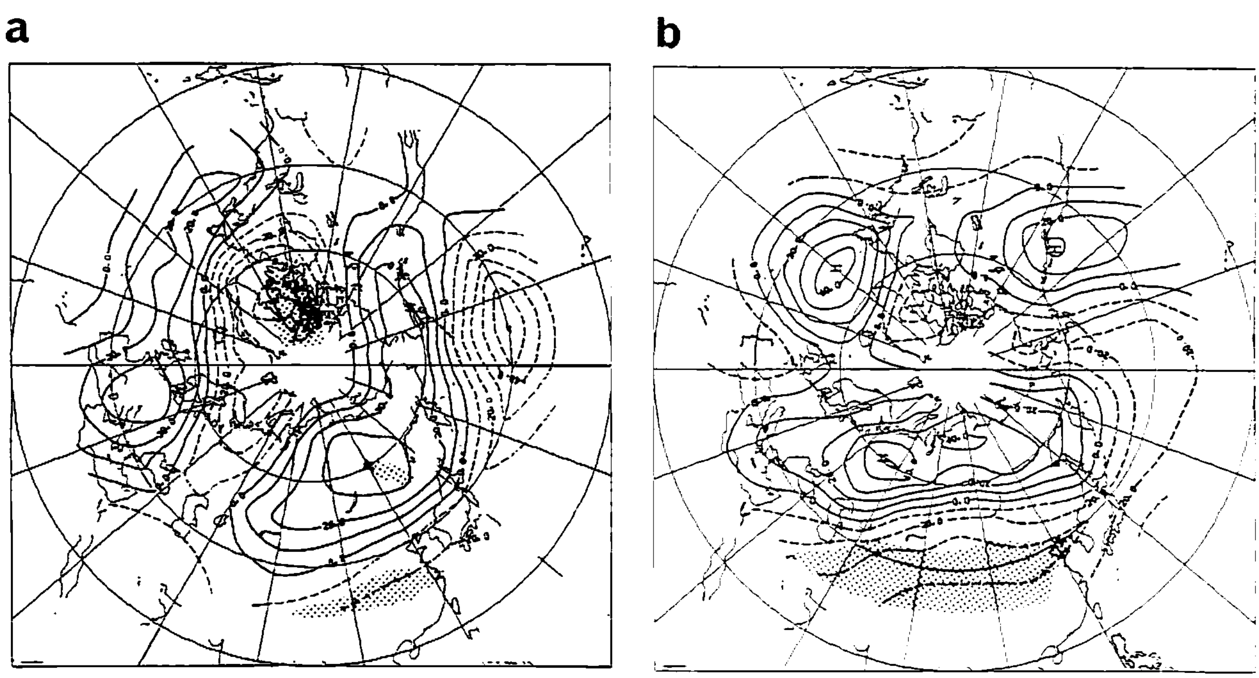


Figure 3. Composite Height Anomaly Chart at 500 mb for Cold Waves (a) The Yunnan Mode (b) The Plain Mode

Units are 10 gpm. Negative values are shown with dashed lines. Areas exceeding 5% significant t-values are hatched.

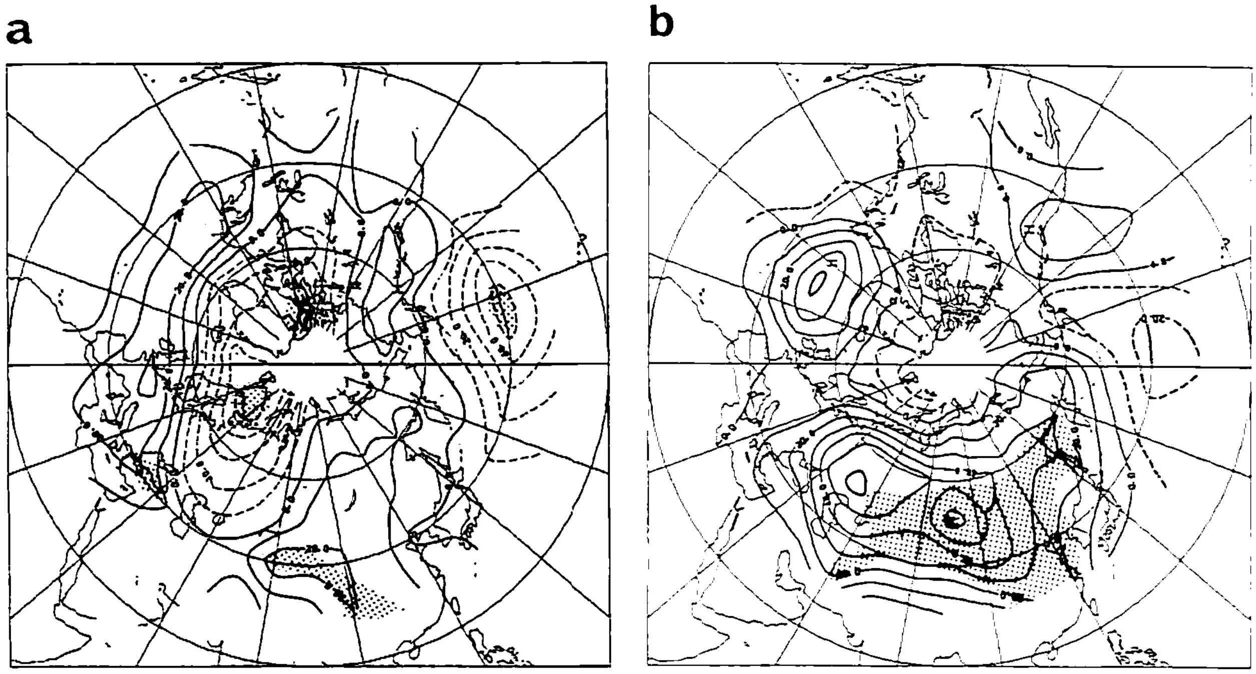


Figure 4. Composite SLP Anomaly Chart for Cold Waves (a) The Yunnan Mode (b) The Plain Mode. Units are 0.1. Negative values are shown with dashed lines. Areas exceeding 5% significant t-values are hatched.

as the so-called Eurasian Pattern (WALLACE and GUTZLER, 1981) in the large-scale atmospheric teleconnection patterns.

Fig. 4 shows the same composite charts but for the SLP anomalies. The anomaly patterns over the western part of Eurasia through the North American sector are very similar to those of 500 mb anomalies. Over the eastern part of Eurasia, in contrast, the anomalies of the opposite sign to those at 500 mb, i.e., the positive anomalies are dominated commonly in the two modes, which may imply a strong baroclinic nature of the anomalies in the lower troposphere over there. The large center of positive anomalies is noticeable over central Siberia near 50°N in the Plain mode (Fig. 4(b)), while a center is located just to the north of the Tibetan Plateau in the Yunnan mode (Fig. 4(a)). This strongly suggests that in the Plain mode the Siberian High is totally intensified with little or no shift of the center position, while in the Yunnan mode a considerable shift of the High toward the Tibetan Plateau and South China is noticeable (Fig. 4(a)).

V. SUMMARY AND DISCUSSION

The EOF analysis of monthly temperature anomalies for the Yunnan Province and for the whole of China has apparently evidenced that the types of cold waves (or surges) dominantly affecting the whole province are different from those affecting the main part of the China Plain. The spatial patterns of the dominant EOFs in the Yunnan mode and the Plain mode suggest that the cold waves dominantly affecting the whole province seem to be part of those coming down from the Tibetan Plateau and/or coming along the northern periphery of the Plateau and passing through toward the southernmost part of China (see Fig. 2(b)). In contrast, those contributing to the Plain mode seem to be derived from the north(west) of China and spread over the whole part of the plain in south China but marginally affect the mountainous Yunnan Province.

The atmospheric circulation patterns associated with these two modes of cold waves (i.e., the Yunnan mode and the Plain mode) show remarkably contrastive features between the two, particularly over central Asia through the North Atlantic polar region. For the Plain mode, the low-index type circulation particularly over the eastern part of the Eurasian continent seems to be important. On the other hand, the teleconnections far windward associated with the Eurasian pattern and the North Atlantic Oscillation (e.g., van LOON and ROGERS, 1978) seem to be greatly responsible for the Yunnan mode. It is noteworthy to state that this circulation pattern for the Yunnan mode is very similar to that for the large extent of snowcover over central Asia (MORINAGA and YASUNARI, 1987). That is, this circulation pattern (Fig.3(a)) seems to be closely related to the extratropical cyclone activity and cold surges in the lower latitudes of the Eurasian continent, particularly to the west of the Tibetan Plateau.

In this case, the actual cold surges to the Yunnan Province seem to come along the northern and eastern periphery of the Plateau as a coastal Kelvin wave (SUMI, 1985; NAKAMURA and DOTANI , 1985; SUMI and TOYOTA, 1988), which may originate from disturbances in the windward side of the plateau. It is interesting to note that under this anomalous circulation field around the Tibetan Plateau cyclonic disturbances occasionally tend to be formed and propagate along the southern periphery of the Himalayas, synchronized with the movement of cold surges along the northern periphery of the Plateau (MURAKAMI, 1981). These disturbances seem to supply abundant moisture from the Bay of Bengal to Yunnan Province. The abnormally heavy snowfall over the northern part of the province in December 1983 occurred exactly under this condition.

As a conclusion, we may emphasize the further requirement for dynamic as well as observational study on the local response of circulation around the Tibetan Plateau to a large scale outbreak of cold airmass windward, particularly over central Asia through the North Atlantic. This may be a key issue for the medium- and long-range forecasting of cold surges in Yunnan Province.

Acknowledgements

We are grateful to Mr. ZHU Yun-he, Mr. FAN Ping of the Meteorological Bureau of Yunnan Province, Mr. GAO Zhi-Cheng, and Mr. SHEN Zexin of the Meteorological Institute of Yunnan Province for providing us with the meteorological data sets and for their stimulative discussion. We also thank Ms. XIE Si-mei of the State Oceanographical Bureau for supplying us the monthly meteorogical data for China. This study is part of the Japan-China cooperative study under a grant-in-aid by the Ministry of Education, Science and Culture in Tokyo, Japan (Leader: Masatoshi YOSHINO, No. 63041025).

(Received Oct. 14, 1989)
(Accepted Jan. 15, 1990)

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中国雲南省における寒波の型と，それに関連した大気循環場について

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中華人民共和国の雲南省全域における寒波の時空間構造を、28年間（1958～1987）の冬（12，1，2月）の月平均気温偏差に主成分分析の手法を適用することにより調べた。また，卓越する寒波のモードが，中国全域に影響を及ぼす寒波の卓越モードと，どのような関係にあるかを，中国全土160地点の同じデータの主成分分析の結果と比較することにより，考察した。その結果、雲南省全域で最も卓越する寒波の型は、より巨視的にみると，チベット高原から雲貴高原，さらに華南南部にかけての山岳・丘陵地にのみ集中して襲来する寒波（雲南モード）に対応していること、これに対し，長江の中・下流を中心として中国平原部全域に最も卓越する寒波（平原モード）の影響は，雲南省では比較的小さく，よりローカルであることがわかった。雲南モードの寒波は，チベット高原から吹き降りて来る寒気団と，高原北（東）縁を地形に沿って流れ降りて来る沿岸ケルヴィン波的な寒気団の振舞いが重要であることも示唆された。

これら二つの寒波のモードに対応する大規模循環場を，北半球全域の500 mb 高度偏差と、地上気圧偏差の合成図手法により，調べた。その結果，雲南モードは，偏西風の遙か風上側である、ユーラシア大陸西部と北大西洋からグリーンランド付近での循環場の偏差と密接に関連していること，これに対し，平原モードは，中国北東方のシベリア中・東部での低指数型循環と寒気団の南下に，より直接的に対応していることが明かとなった。

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