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THE CHARACTERISTICS OF 500 hPa GEOPOTENTIAL AND SST FIELD OF EXTREMELY SEVERE COLD MONTHS IN SOUTH CHINA WINTER

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ABSTRACT: The region of south China is sometimes subject to major climatic catastrophes in winter. To have a clear understanding, the time in which extremely severe cold months occur in the south China wintertime over the past 45 years are determined and characteristics of the 500-hPa geopotential fields and SST fields are studied for the simultaneous and preceding 6-month periods. Similarity exists in the 500-hPa geopotential fields between each current severely cold month, with the geopotential pattern of being high in the north, but low in the south, of Asian-Pacific region and meridional circulation developing. The work presents anomalies of the months with significant differences in the 500-hPa geopotential field of the previous periods. The SSTA is continuous in the distribution from each extremely severe cold winter month back to the 6 months leading up to it for the region of south China while the SST pattern is of El Niño in January and the preceding 1 ~ 6 months for equatorial eastern Pacific but of La Niña in February and December. It is concluded that the prediction of severely cold winter months are possible with the use of the geopotential field at 500 hPa and the SST fields for the months ahead of the target time.

Key words: extremely severe cold months in south China winter; 500-hPa geopotential field; SST field; characteristics

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1 INTRODUCTION

Due to its location in the southern part of the subtropical zone, the south China region is subject to, in most of the time, weakened flows of cold air progressing southward, though with occasional processes of sustained cold temperature and rainy weather over extensive areas, resulting in serious damages from coldness. For instance, a strong cold air surge taking place in the second and third pentads of December 1975 brought about a large fall of temperature over most of the south China region, with the diurnal temperature in northern Guangdong and Guangxi dropping continually by 20°C and there were widespread frosting and icing as well as rain, snow and strong winds. The air temperature reduced to 0 ~ 4°C even in the southern part of south China. The cold surge is rare in historical records ever existent by the vast areas it affects, long duration it lasts, temperature fall it causes and windy and snowy weather it inflicts with. It is of the possibility of once every 80 years. The unusually strong cold damage in south China is therefore included as one of four climatic disasters of wintertime in China[1].

Being an anomalous climatic disaster, extremely severe cold months in the south China winter appear once every 30 ~ 40 years, which is a small probability event. Up till the present, not much

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work has been devoted in this aspect. In their *Atlas of Seasonal Distribution of Climatic Disasters in China (1951–1990)*, Huang et al. (1997) presented statistic distribution of 7 climate-induced disasters in individual seasons of the year from 1950 to 1990 in China and comprehensive summaries of them over the past 40 years. The description includes the intensity of cold waves on a yearly basis in wintertime for this region and lists the top three winters by the degree of cold surge. Wang, Gong and Chen[2] studied the occurrence of years with 9 severe climatic (and national) disasters on the seasonal scale for the past 118 years. In spite of it, research on predicting major climate-based disasters has not been much up to the present time.

Setting the month as the temporal scale, the current work first determines the years in which severely cold winter months appear over the past 45 years in south China and then studies the 500-hPa geopotential fields and SST fields in simultaneous and preceding periods relative to the appearance.

2 DATA AND METHODS

The mean air temperature for individual winter months in south China from 1951 to 1995 are represented by mean values from 15 observation stations at Xiamen, Meixian, Shantou, Qujiang, Heyuan, Guangzhou, Yangjiang, Zhanjiang, Haikou, Guilin, Liuzhou, Wuzhou, Nanning, Beihai, and Baise. The data are retrieved at the National Climate Center.

The geopotential field (2.5°×2.5°) at 500 hPa for 1950 ~ 1995 and the SST (1°×1°) use NCEP/NCAR reanalyzed data.

Composite analysis and statistic methods are used to study the 500-hPa geopotential and SST fields in the extremely severe cold months.

3 DETERMINATION OF EXTREMELY SEVERE COLD WINTER MONTHS

In accordance to specifications of the World Meteorological Organization (WMO) and a number of countries, events with the anomaly being 2 times as much as the standard deviation ($2s$) are defined to be anomalous and events with the anomaly being $1.3s$ are described to be severe. If a particular element varies following the normal distribution, then the probability of $\geq 2s$ or $\leq -2s$ is 2.28%, which is equivalent to about 1 incident every 40 years; the probability of $\geq 1.3s$ or $\leq -1.3s$ corresponds to the frequency of about once every 10 years.

Tab.1 gives the anomalies of the lowest 8 mean temperature in January, February and De-

Tab.1 Anomalies of monthly mean temperature in extremely severe cold, severe cold and cold months in 1951 ~ 1995 in the south China wintertime (unit: °C)

	Jan. s =1.38			Feb. s =1.32			Dec. s =1.84		
	year	ΔT	$\lvert\Delta T\rvert/s$	year	ΔT	$\lvert\Delta T\rvert/s$	year	ΔT	$\lvert\Delta T\rvert/s$
Extremely severe cold	1977	-2.9	2.1	1968	-4.7	3.6	1967	-2.8	1.5
	1984	-2.5	1.8	1957	-3.4	2.6	1975	-2.8	1.5
Severe cold	1963	-2.1	1.5	1969	-2.2	1.6	1982	-1.9	1.0
	1955	-1.8	1.3	1964	-2.2	1.6	1954	-1.6	0.9
	1962	-1.7	1.3	1984	-2.2	1.6	1983	-1.5	0.8
Cold	1971	-1.6	1.2	1980	-1.9	1.4	1973	-1.3	0.7
	1956	-1.3	0.9	1977	-1.8	1.4	1952	-1.2	0.7
	1970	-1.2	0.9	1974	-1.7	1.3	1981	-1.1	0.6

cember 1951 ~ 1995 and corresponding values of $|\Delta T|/s$.

From the figure, it is known that over the 45-year course the extremely severe cold months with $|\Delta T|/s \geqslant 2$ appear in only 3 months, January 1977, February 1968, and February 1957, while they are absent in December. Since 1951, there have been an extremely severe cold months in the 1950's, 1960's, and 1970's, separately, occurring about once every 10 years. For January and February each, the chance is about 1 ~ 2 incidents every 40 years. It is apparent that there have not been any extremely severe cold months in south China since the winter of 1976/77. It is associated with the tendency that warm winters have been dominant in the past dozen years or so in China and reflects on the obvious warming trend in the wintertime air temperature in south China.

To conduct a composite and comparing study rather than just a case study, the work approximates January 1984 (with $|\Delta T|/s \geqslant 1.8$), December 1967 and December 1975 (with $|\Delta T|/s \geqslant 1.5$ in both cases) to be the extremely severe cold months. The months which rank from the third to fifth place are listed as the severely cold months.

The extremely severe cold months for the south China winter as defined in this work are in consistence with Huang et al. (1997) and Wang et al. (1999). For instance, the two months that are determined to be within this category, December 1975 and January 1977, are just the toppest 2 winter seasons of 1975/76 and 1976/77 when the cold waves strongest for the previous 40 years hit the region. The fitting shows that such low-temperature months are caused by more than one process of cold waves. The extremely severe cold months of February 1957, February 1968, and January 1977, as determined by our criteria in this work, are actually components of the extremely severe cold winters in 1956/57 and 1967/68 and the severely cold winter in 1976/77 across the nation, as given in Wang et al. (1999). It is suggested that only when there is a nationwide cold winter would the south China region has the extremely severe cold months, which is also indicating that cold air active in these months all originate from the northern parts of China.

4 MONTHLY MEAN 500 hPa GEOPOTENTIAL FIELDS IN EXTREMELY SEVERE COLD MONTHS OF SOUTH CHINA WINTER

4.1 *500-hPa geopotential fields for the simultaneous periods*

Fig.1 gives the anomalies of the field for the study of how the geopotential field at 500 hPa behaves in the extremely severe cold months in south China.

A general feature in this anomaly figure is that the geopotential anomalies in the middle and higher latitudes of the Asian-Pacific region are basically allocated in a high-north vs. low-south pattern. Blocking highs intensely develop in the high latitudes and cold vortexes deepen and move southward in the middle latitudes, in association with dominant meridional circulation, strong winter monsoon in East Asia and weak subtropical high in the west Pacific. In the meantime, two major meridional troughs deepen in East Asia and North America and the high-pressure ridges in front of the Ural Mountains and western North America develop northward. Tab.2 gives the location and intensity of the anomalous centers of the 500-hPa geopotential fields in the Asian-Pacific area for the extremely severe cold months (figure omitted) and severely cold months (figure omitted) in the south China winter. It is known therefrom that:

(1) The centers of positive anomalies in northern Asia are more northward / eastward located and stronger in extremely severe cold months than in severe cold months or cold months;

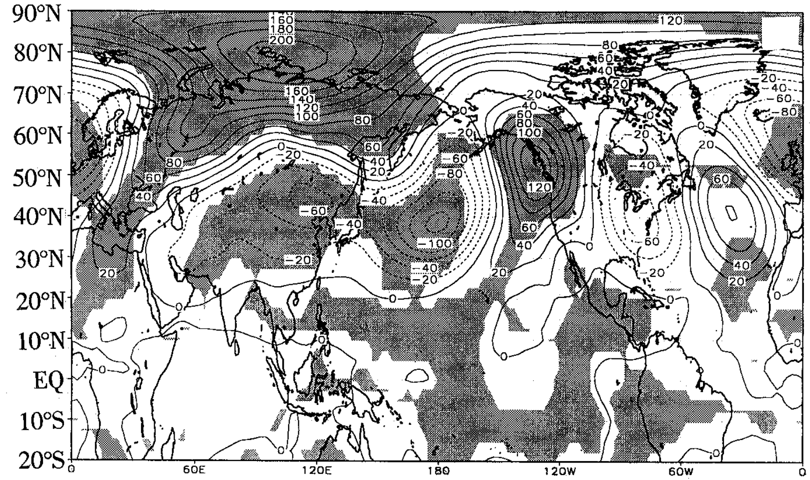

Fig.1 Composite anomalous chart of 500 hPa geopotential fields in the extremely severe cold months (January) in the south China winter (unit: gpm, shaded area for identical anomalous signs)

(2) The centers of positive anomalies are the strongest in January (200 geopotential meter, shortened as gpm), followed by Februay (120 gpm), with December having the least intensity (80 gpm);

(3) The centers of negative anomalies in southern Asia are also show the largest intensity in January (–120 gpm) while February and December being relatively weak; and

Tab.2 Location and intensity of anomalous centers of 500 hPa geopotential fields in simultaneous periods of the extremely severe cold, severe cold and cold months in the south China winter

		pos.anomaly centers in n.A-P			neg.anomaly centers in n.A-P			Anomaly
		lat./°N	long./°E	int./gpm	lat./°N	long./°E	int./gpm	int.s.c.
Jan.	e.s.c.	78	105	200	38	180	-120	0
	s.c.	57	105	100	35	135	-80	-20
	cold	48	50	60	28	140	-40	-10
Feb.	e.s.c.	65	120	120	40	105	-40	-30
	s.c.	65	55	120	48	95	-20	0
	cold	65	60	40	50	160	-20	0
Dec.	e.s.c.	65	100	80	35	120	-40	-20
	s.c.	60	80	60	35	90	-20	0
	cold	55	70	40	40	140	-20	0

Note: e.s.c. stands for extremely severe cold; s.c. for severe cold; pos. for positive; neg. For negative; n.A-P for northern Asian-Pacific region; s.A-P for southern Asian-Pacific region; int. for intensity; s.c. for intensity in south China region.

(4) The intensity of both positive and negative anomalies in extremely severe cold months are larger than in severely cold or cold months.

To summarize, January has the most significant characteristics of 500-hPa geopotential anomalies among the extremely severe cold months in the south China wintertime. It is marked by a geopotential anomaly of being high in the north and low in the south in the Asian-Pacific area, indicating the arrival of very strong cold air mass in the south China region. In company of the feature, three important troughs and ridges in the planetary waves of the Northern Hemisphere are all in a stage of vigorous enhancement.

The current work makes additional attempts to study the geopotential fields at 200 hPa in the months of the extremely severe cold, severe cold, and cold temperatures in south China. The result shows that the distribution of the anomalies is very similar to that of the 500-hPa field. It suggests that there are similar variations with the middle and upper levels of the troposphere in the three categories of cold winter months. Specific results are not discussed here.

4.2 *500-hPa geopotential fields for the preceding periods*

To study the 500-hPa geopotential fields in the preceding months, the anomaly charts of composite geopotential heights (omitted) are computed for the preceding 1 ~ 6 months and a significance level test is done for each of them for derivation of the *t* statistics.

$$t = \frac{\overline{H}_1 - \overline{H}_2}{n_1 s_1^2 + n_2 s_2^2} \sqrt{\frac{n_1 n_2}{n_1 + n_2}(n_1 + n_2 - 2)}$$

where $\overline{H}_1$, $\overline{H}_2$ and $\overline{s}_1$, $\overline{s}_2$ are the mean and root-mean-square error of the 500-hPa geopotential field for the extremely severe cold months and multi-year mean respectively, and n_1 and n_2 are the number of years in which there are the extremely severe cold months and for which the multi-year mean is derived, respectively. Tab.3 gives the percentage of grid points with significance level greater than 0.05 as compared to the total in various extremely severe cold

Tab.3 Percentage of grid points with significance level greater than 0.05 as compared to the total in various extremely severe cold months in 1 ~ 6 months prior to the extremely severe cold month

	1	2	3	4	5	6
Jan.	9.5(Dec.)	20.8(Nov.)	36.8(Oct.)	0.8(Sep.)	5.7(Aug.)	3.4(Jul.)
Feb.	2.6(Jan.)	5.0(Dec.)	4.2(Nov.)	0.5(Oct.)	3.0(Sep.)	1.0(Aug.)
Dec.	1.6(Nov.)	0.3(Oct.)	2.8(Sep.)	3.1(Aug.)	4.5(Jul.)	2.5(Jun.)

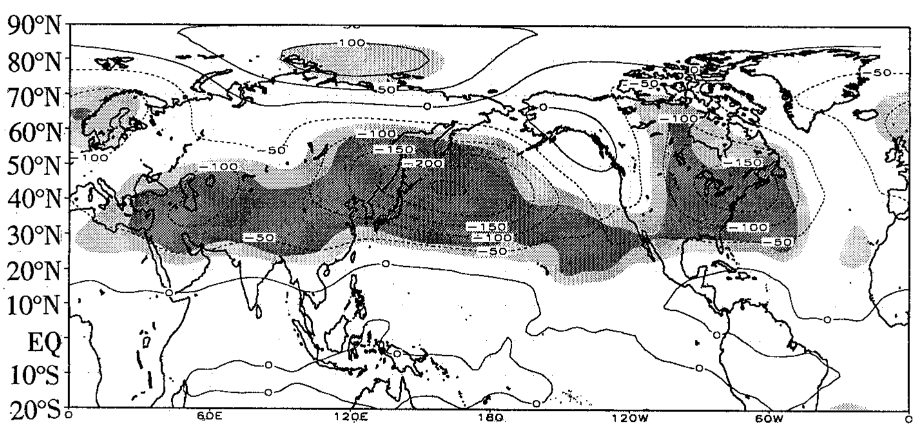

Fig.2 Same as Fig.1 but for periods prior to the extremely severe cold months (the last October before the extremely severe cold January); unit: gpm, black and light black shades for areas with grids being 0.02 and 0.05 level of significance, respectively

months in 1 ~ 6 months prior to the extremely severe cold month. It is clear that for the third month before January (i.e. the last October), the second month before February (the last December) and the fifth month before December (the last July), they are the months that have the highest percentage among the 6 months leading up to individual extremely severe cold months. Fig.2 is the 500-hPa geopotential anomaly of the preceding October (3 months) before the extremely severe cold month of January.

It is known from Fig.2 that the third month before the extremely severe cold January, i.e., the preceding October is characterized by a zone of negative anomalies from 20°N to 70°N at the 500 hPa geopotential field, with three centers of negative anomaly (having a 0.02 significant test confidence) distributed in the northeast Asia—northwest Pacific (–250 gpm), eastern North America (–150 gpm) and the Caspian Sea (–100 gmp). There is a well-defined center of positive anomaly (significance level at 0.05) within the Arctic Circle (100 gpm). The distribution of anomalies shows that the three upper-level troughs are stronger than normal at the 500-hPa level in the Northern Hemisphere. It is noted that the anomaly chart (figure omitted) of the geopotential anomaly at 500 hPa for the preceding November is similar to and takes up greater percentage than October. It is therefore possible to take the 500-hPa-geopotential field for these two months as a precursory sign for the appearance of the extremely severe cold months.

For the two months (December) before the extremely severe cold February, the 500-hPa geopotential field is marked by a center of positive anomaly with significance level of 0.05 in northwestern Siberia (140 gpm) and a negative anomaly center in the Bohai Bay in northern East Asia. It implies that the blocking high is vigorously developing in northern Asia. There is also a significant center of positive anomaly from eastern north Pacific to western North America, suggesting a strong East Asia trough. For the preceding November, the 500-hPa geopotential field is similar to that for December (figure omitted) and with a higher percentage of appearance. It is for this reason that the 500-hPa geopotential field in these two months can also be used as a precursory signal.

The common outstanding feature of the 500-hPa geopotential field of July which is prior to the extremely severe cold December is that the negative center in northern and eastern North America all correspond to the 0/05 confidence level. It is also a predictive signal that can be considered for use.

5 SST FIELDS IN EXTREMELY SEVERE COLD MONTHS OF SOUTH CHINA WINTER

5.1 *SST fields for the simultaneous periods*

The current work follows the definition and codes as specified in the *Bulletin of Climatic Monitoring* by the National Climate Center of China. The NINO1+2 is situated within 0º ~ 10°S and 80°W ~ 90°W, NINO3 within 5°N ~ 5°S and 90°W ~ 150°W, and region B within 10°N ~ 0° and 50°E ~ 90°E. In the meantime, the current work defines the Pacific waters within 30°N ~ 50°N and west of 150°W to be northwest Pacific (simplified as NWP), the Pacific waters within 10°N ~ 10°S and east of 150°W to be equatorial eastern Pacific, and the South China Sea to be SCS.

Both Fig.3 and Tab.4 present the main characteristics of the SST fields in the extremely severe cold winter months of south China as follows.

January: Vast areas of positive anomalies are present in NINO1+2, NINO3 and regions south to it as well as in waters off the west coast of North America, with two largest centers at (22°S, 115°W) and (25°S, 75°W) both being +1.5°C. A significant zone of negative anomaly exists in the

Tab.4 Signs of SST anomalies in and prior to the extremely severe cold months of south China winter

	Jan.	The year before			Feb.	The year before			Dec.	Preceding periods		
		Jul.	Sep.	Nov.		Aug.	Oct.	Dec.		Jun.	Aug.	Oct.
NINO 1+2	+	+	+	+	-	-	-	-	-	-	-	-
NINO 3	+	+	+	+	-	-	-	-	-	-	-	-
EQP	+	+	+	+	-	-	-	-	-	-	-	-
B	/	/	/	/	-	-	-	-	-	-	-	-
NWP	-	-	-	-	+	+	+	+	+	+	+	+
SCS	/	/	/	/	-	-	-	-	-	-	-	-

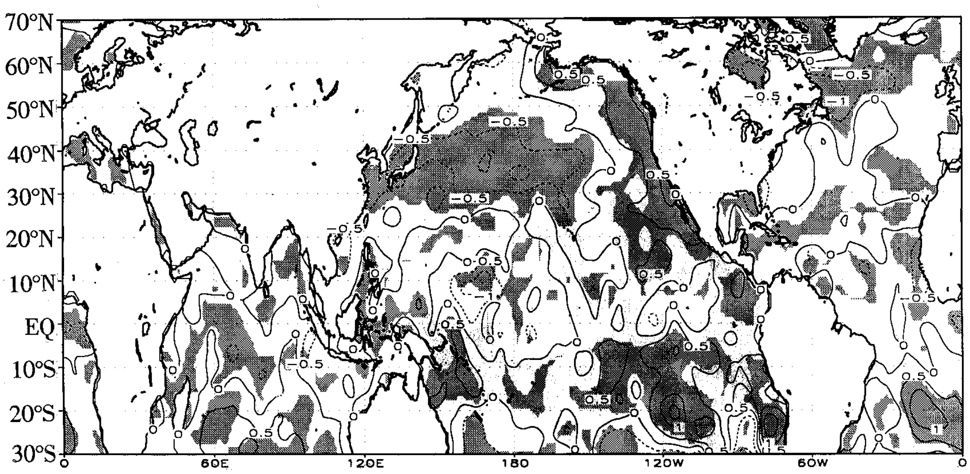

Fig.3 Same as Fig.1 but for SST (unit: °C); shaded areas are of the same signs of anomalies

NWP region, having a minimum of –1.0°C near the center.

February: NINO+2, NINO3, EQP, west Pacific, South China Sea and Region B are of significant negative anomaly while the NWP and central and eastern Pacific are of positive anomaly.

December: Apart from the NWP region where there is well-defined positive anomaly, the Pacific Ocean and Indian Ocean are of significant negative anomaly, particularly in the EQP and areas south of it.

It is clear from the study above that the SST in the extremely severe cold month of January in the south China winter is roughly in opposite distribution with that in the other two months February and December. In January, the SST is positively anomalous in NINO1+2, NINO+3 and EQP but negatively anomalous in NWP. In contrast, February and December see negative anomalies of the SST in NINO1+2, NINO3 and EQP but positively anomalies in NWP. It is a point worth much attention.

5.2 *SST fields for the preceding periods*

Figs.4, 5, and 6 and Tab.4 give the SST anomalies in the 6th,4th, and 2nd month before the extremely severe cold months of January, February, and December in the south China wintertime (omitting the figures for the SSTA in the 4th and 2nd month before). We know therefrom that:

(1) Good persistence exists in the variation of the SST fields of July, September, and November of the previous year, i.e., the 6th, 4th, and 2nd month before January. It is marked by the features listed below: firstly, there is a large area of significant positive anomaly in equatorial eastern Pa-

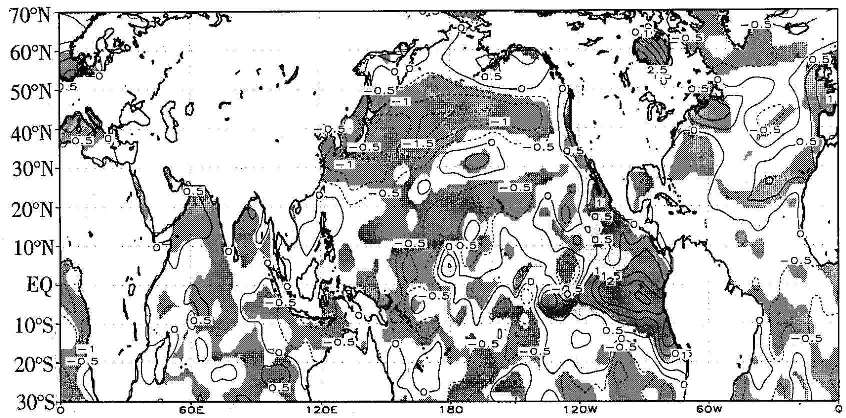

Fig.4 Composite SSTA in the period prior to the extremely severe cold January (July in the year before) in south China winter

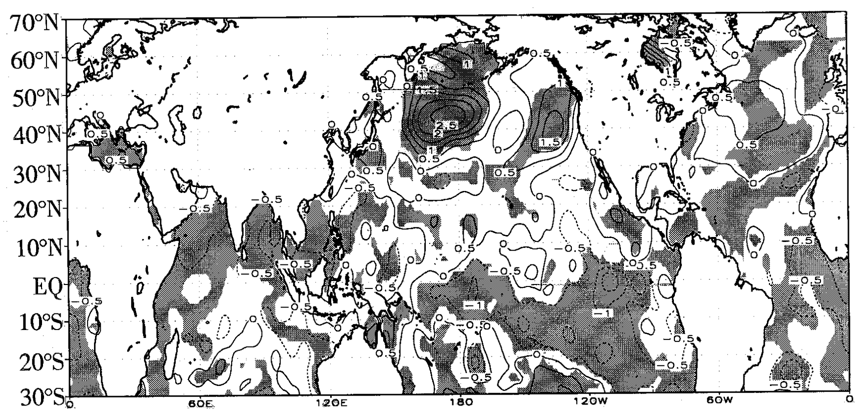

Fig.5 same as Fig.4 but for the extremely severe cold February (August in the year before)

cific, which is the maximum in July at 2.5°C but decreases gradually afterwards, being 2.0°C in September and 1.0°C in November. Such characteristics of the SST suggest that for the 6^{th} month before the extremely severe cold January the El Niño episode is decaying, which agrees in fact with the observation. Corresponding to January 1977, an extremely severe cold month, a weak El Niño episode was decaying during the period from January 1977 to June 1976. Corresponding to January 1984, another extremely severe cold month, is a strong El Niño episode from September 1982 to September 1983[3]. Secondly, the negative SSTA is significant in the northwest Pacific Ocean, ranging from –1.5°C to –1.0°C. From the preceding 6^{th} month to the current month of the extremely severe cold January, positive SSTA in the EQP and negative SSTA in the NWP all show signs of persistence.

The above two features are also quite obvious in the current extremely severe cold month of January. It is believed, therefore, that there is persistence in the positive SST anomaly in EQP and negative SST anomaly in NWP from 6 six months before to January.

(2) For the 6^{th}, 4^{th}, and 2^{nd} month before the extremely severe cold February, i.e., August, October, and December of the previous year, the variation of SST shows a good persistence.

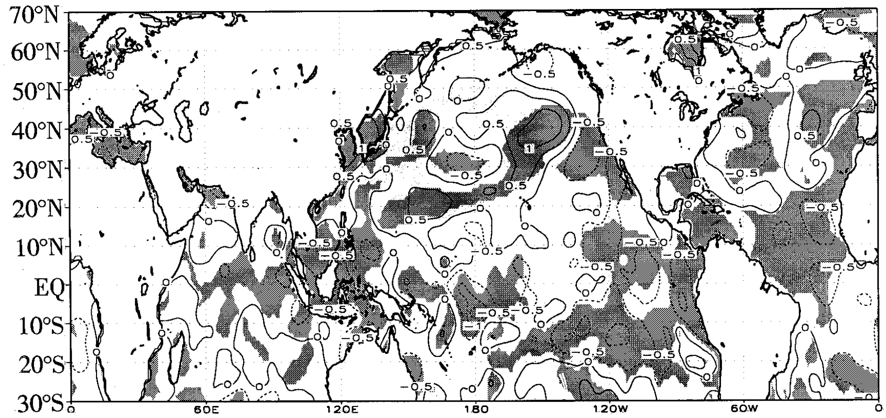

Fig.6 Same as Fig.4 but for the extremely severe cold December (June in the year before)

NINO1+2, NINO3, EQP, Region B, and SCS are of significant negative anomalies, with the largest negative anomaly (–2.0°C) in the NINO1 in October and NINO3 in December. It is generally the same with that for the current month of February.

(3) In June, August, and October prior to the extremely severe cold December, the SST varies in much the same way as that in the preceding periods for the extremely severe cold month of February — apart from the NWP region where there is positive anomaly, most of the remaining region is of negative anomaly. The largest negative anomaly is –2.0°C in the EQP region in the preceding October. It is also generally the same with that for the current month of December.

For the 6th month before the extremely severe cold months of February and December, the SST in the EQP region is usually of the La Niña phenomena. As a matter of fact, of the four previous periods for the four extremely severe cold months, two preceding periods, one from the second quarter of 1954 to the third quarter of 1956 prior to February of 1957 and the other from the first quarter of 1975 to the fourth quarter of 1975 prior to December 1975, show features of the La Niña phenomena[4]. On the other hand, the SST is of negative anomaly in the EQP region during December 1967 ~ February 1968. It is then clear that the extremely severe cold months of February and December coincide with the decaying stage of the La Niña event or the negative phase of the SST in eastern equatorial Pacific.

It is suggested in the above analysis that the variation of SST from the current extremely severe cold month to 6th month prior to it is of significant persistence. From the current extremely severe cold month of January to the 6th month before, the EQP SSTA is of decaying El Niño episode while February and December are of La Niña episode.

6 CONCLUDING REMARKS

a. For the past 45 years, three extremely severe cold months have appeared in the south China winter, each distributing in the 1950's, 1960's, and 1970's (February 1957, February 1968 and January 1977), occurring about once a decade. There has not been a single incidence of the extremely severe cold month since the 1980's. High consistence is found between the extremely severe cold months of south China and those and severe cold months on the national scale. In other words, only when the extremely severe cold or severe cold months occur across the whole nation, could the extremely severe cold months be recorded in south China.

b. For the simultaneous periods of the extremely severe cold months in south China, the 500-hPa geopotential fields are high in the north but low in the south with blocking situations in the middle and higher latitudes Asia and strengthened meridional circulation. It is characteristic of the points below in the preceding periods: three of the stationary upper-level troughs deepen in the Northern Hemisphere in October and November prior to the current January; blocking patterns develop in northern Asia in December and November prior to the extremely severe cold February; the negative center in the northern part of North America and positive center in the eastern part are significant in July prior to the extremely severe cold December.

c. Good persistence is shown in the SST from the current extremely severe cold months of the south China winter to the 6^{th} month before. Persistent positive anomaly is with the SST in the equatorial eastern Pacific from the extremely severe cold January to the 6^{th} month before and the feature tends to weaken, having the signs of a decaying El Niño event, with the northwest Pacific Ocean dominated by negative anomaly. In contrast, persistent negative anomaly of SST is found in the equatorial eastern Pacific from the extremely severe cold February and December to the 6^{th} month before and the feature is of La Niña event. Positive anomalies prevail in the northwest Pacific and negative anomalies in the South China Sea and the equatorial Indian Ocean.

In summary, the characteristics of the 500-hPa geopotential field and SST field in periods leading up to the extremely severe cold winter months in south China can be taken as precursory signals to predict the occurrence of these months. Other physical factors, such as the subtropical high in the west Pacific, the winter and summer monsoons in East Asia, the polar vortexes in Asia, perpetual snow and polar ice, etc., are to be discussed in separate papers.

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