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CLIMATOLOGICAL DIAGNOSIS OF WINTER TEMPERATURE VARIATIONS IN GUANGDONG

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ABSTRACT: Using the monthly mean and minimum temperature data of the 36 observation stations in Guangdong, the climatological features of the temperatures have been analyzed, including characteristics of trends, abrupt changes and periods. And the possible affecting factors on the winter warming in Guangdong have been discussed. The results show that the winter temperatures, particularly the monthly mean minimum temperatures in Guangdong, have a warming trend. The rise of the winter minimum temperatures in Guangdong began in the second half of 1960's and the warming was more evident since the 1980's.

Key words: climatological diagnosis; winters; temperature

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1 INTRODUCTION

For the past 100 years, the climatic warming across the globe has been evident in that the average air temperature has risen by about 0.3°C ~ 0.6°C. The temperature rise on the surface of the Northern Hemisphere has been significant since the end of the 1970's and it is actually the warmest period in the 20th century. As is shown in the results (Ding and Dai, 1994; GMBA, 1987; Wang and Ye, 1995; Jiang and Ding, 1996), the trend for temperature to vary over the past 40 years in China is generally similar to that over the world — it is marked by temperature ascent, chiefly displayed during wintertime. What is different from the global trend is that the rise of air temperature from the 1970's is within that around the 1940's.

Complication sums up the climatological variation in air temperature in China while the Guangdong has its own characteristics. Previous study in this respect has been mainly on the average variation (GMA, 1987), such as the distribution of mean temperature and variation patterns of air temperature over the past hundred years. In their recent work, Wu and Zhang (1996) compare the linear trend on a hundred-year scale of mean temperature, abrupt change points on decadal scale variations and local temporal structures on finer scales for Guangzhou and Northern Hemisphere. It remains rather rough in its attempt to investigate how air temperature varies in winter Guangdong. Work on winter temperature in Guangdong, especially in questions as how the minimum temperature varies and what causes it, has been dealt with insufficiently. It is, then, necessary to work on it.

Taken as basic objects in this study, mean temperature and minimum temperature of individual winter months from 1960 to 1996 from 36 meteorological observation stations in Guangdong province are used to analyze the climatological variation, focusing on dynamic variation.

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2 DATA

The data from the 36 stations are from December to February in 1960 to 1996. Puts through a preliminary quality check, obvious errors in the data have been corrected.

3 SUMMARY OF DISTRIBUTION OF AIR TEMPERATURE IN WINTER GD

There is not difference in the pattern of distribution of mean and monthly minimum air temperature over each of the winter months in Guangdong. Distribution maps are presented here only for December ~ February (DJF) (Fig.1). It is then clear that the distribution is cold in north and warm in south and the isothermal contours go east-west over the Leizhou Peninsula where the air

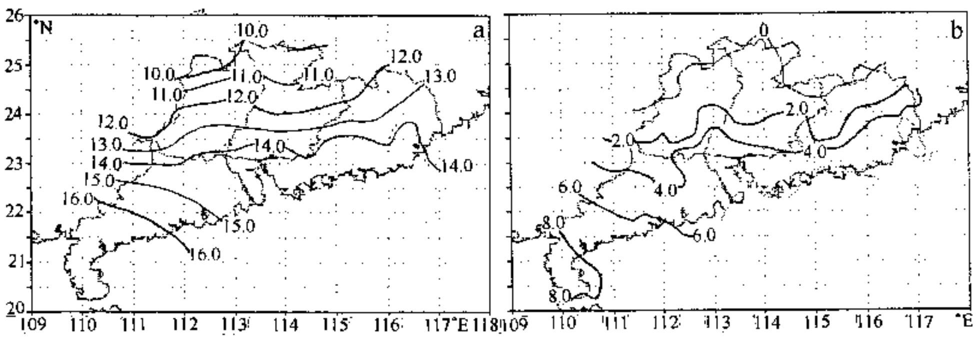

Fig.1 Distribution of winter (DFJ) mean temperature (a) and minimum temperature (b) in Guangdong.

temperature is the highest in the province, whether or not viewing it from winter mean or individual winter month. Performing an EOF decomposition of anomalies of monthly mean and monthly minimum temperature for the months, we find that their first eigenvector take up more than 90% of the total variance, with homogeneous spatial distribution (Figure omitted). It is an indication that the annual variation shows good consistence for the monthly mean temperature and minimum temperature over all parts of the Guangdong province. The time coefficient of the first eigenvector tends to vary in high consistence with corresponding mean Guangdong temperature (a monthly average over the 36 stations, same below) and mean Guangdong minimum temperature (a monthly average over the 36 stations, same below). For each of the interested months, the correlation is high between the series of the mean temperature / minimum temperature and monthly mean temperature and monthly minimum temperature for each of the stations cited, being over 0.85 for most of the stations. It is then concluded that the mean and minimum air temperature in each of the DJF months can well represent the variation tendency in air temperature in Guangdong.

4 DIAGNOSTIC STUDY OF CLIMATOLOGICAL VARIATION OF WINTER TEMPERATURE IN GUANGDONG

4.1 *Estimates of linear tendency*

The tendency of climatic changes is estimated with the least square method having the linear tendency and the results are verified for significance using correlation coefficients. Tab.1 lists the ascending (descending) tendency of variation with the positive (negative) signs of the b value: the larger the magnitude, the higher the rate of rising (falling). Fig.2 gives the curves of anomalous variation of mean and minimum air temperature in Guangdong over each of DJF.

As is shown in the result, the value of b stays above positive throughout all DJF months, being the largest in January. Estimating from the data for the last 37 years, we find that the mean temperature and minimum temperature in January increase linearly at rates of 0.326°C / 10 years and 0.753°C / 10 years, respectively, followed by December. The value of b is near zero for the mean temperature in January, showing no trend of warming, though the minimum temperature increases at 0.467°C / 10 years. For the whole of winter, the mean temperature and minimum temperature increase at a linear 0.183°C / 10 years tendency and 0.544°C / 10 years. It is, therefore, obvious that the warming trend is greater for the minimum temperature than for the mean temperature in each of DJF months. Studying from the correlation coefficient, all linear warming but that for January does not pass the significance test in terms of the minimum temperature and mean minimum temperature. In comparison with all other months of the year, we discover that such warming

Tab.1 The b values and relationship coefficients of monthly mean temperature and minimum temperature in Guangdong (%)

	December	January	February	winter
b value of mean temperature	0.0238	0.0326	0.0003	0.0182
Correlation coefficient R %	18	26	0	21
b value of min. Temperature	0.0412	0.0753	0.0467	0.0544
Correlation coefficient R %	22	47	24	58

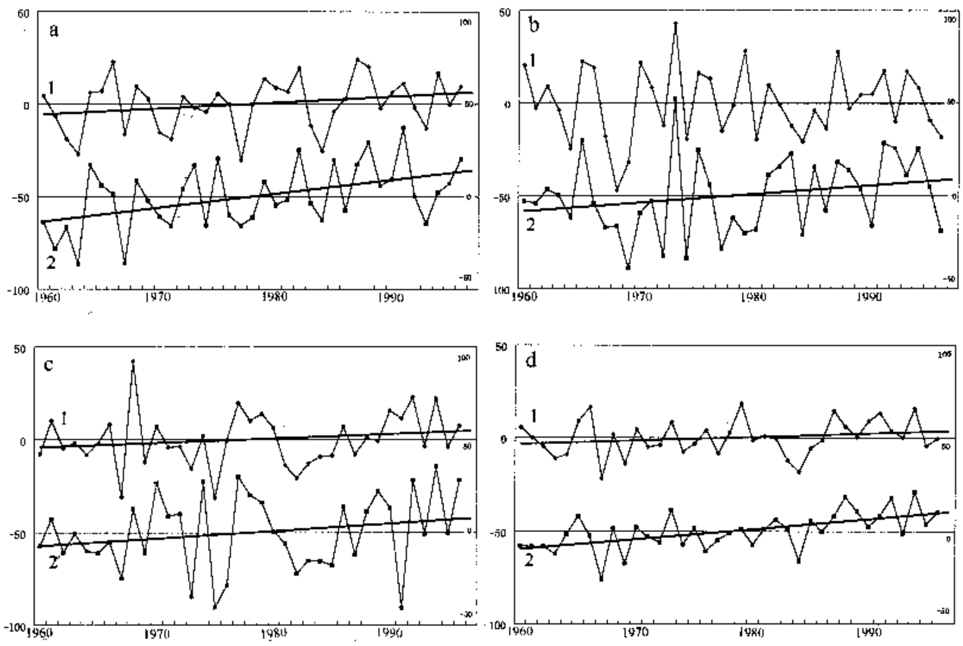

Fig.2 The curves of monthly mean temperature anomalies (curve 1) and mean minimum temperature anomalies (curve 2) in winter. (a) Jan.; (b) Feb.; (c) Dec.; (d) winter

trend is evident, though with winter the strongest season.

The distribution of the b values generally point to regions with considerable warming (figure omitted). In January, the southeast coastal areas of Guangdong is dominated by large-value zones while the western part by small-value ones; in February, however, the large-value zones cover areas north of the Xijiang River and east of the Pearl River Mouth as the small ones shift to the southwestern part; in December, the large-value zones are active over most vast areas of the Pearl River Mouth and coastal areas.

Fig.3 gives the distribution of value b for the mean minimum temperature at all selected stations in Guangdong province. It is shown that the value is larger in the eastern half than in the western half, with Shantou, Huiyang and Shenzhen having the largest and western Guangdong and the Leizhou Peninsula having the smallest. The distribution of the b value for the mean temperature in winter is similar to that for the minimum temperature, though with much smaller magnitude ranging from 0.01 to 0.04.

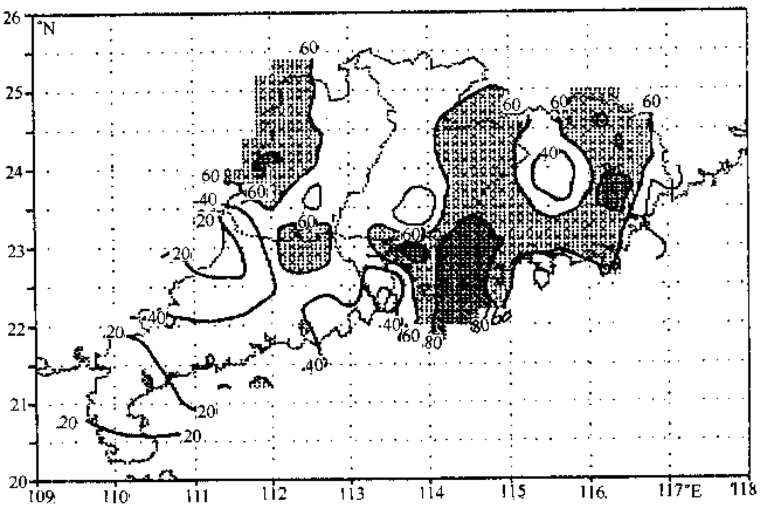

Fig.3 The distribution of the b values for the winter mean minimum temperature in Guangdong (the value in figure is 1000×b)

4.2 *Abruptness and phase*

Abrupt climatic changes are periods in which a climatic state evolves into another state with large difference in between. They can be classified into three basic types of abrupt changes: mean, variability and trend.

The Yamamoto method is one of the techniques to verify the abrupt change by mean value. It is used to verify the series of mean and minimum air temperature in each DJF month in Guangdong, without discovering any significant abrupt change by mean value.

Another type is by the tendency, i.e. it shows substantial changes in the trend of variation. The Mann-Kendall method can serve in this purpose.

For a series $T_i, i=1,2\cdots n,$ a rank-one statistic is constructed as in

$$S_k = \sum_{j=1}^{k} \sum_{i=1}^{j} R_{ij} \tag{1}$$

where

$$R_{ij} = \begin{cases} 1 & T_i > T_j \\ 0 & T_i \le T_j \end{cases} \quad (2)$$

With the assumption that S_k observes the identical distribution at any time, the statistic can be defined as

$$U_k = [S_k - E(S_k)] - \text{sqrt}(\text{Var})(S_k) \quad (3)$$

in which $E(S_k) = k(k+1)/4$, i.e. $\text{Var}(S_k) = k(k-1)(2k+5) - 72.$

Run computation for the statistic U_{2k} following the temporal sequence of T_{2i} and the result is denoted as *UF*. Then, rerun the computation following the sequence of $i = n, n-1, \cdots, 1$ and denote the result as *UB*. *UF* intersects *UB* between lines of confidence before the *UF* line surpasses it. The intersected point is considered where the abrupt change has taken place. In addition, phases of temperature rise and fall can be divided according to the meaning of U_k itself. During the rising phase of *UF*, $T_i > T_j$ When the event of $T_i > T_j$ goes predominantly and the *UF* line goes outside of the confidence line, the suggestion is that such dominance has grown to a level that would never have reached with random settings. Phases like this can then be taken to be warming. Cooling phases can also be determined likewise.

For analyzed results of monthly minimum temperature in Guangdong in each of the DJF months, see Fig.4.

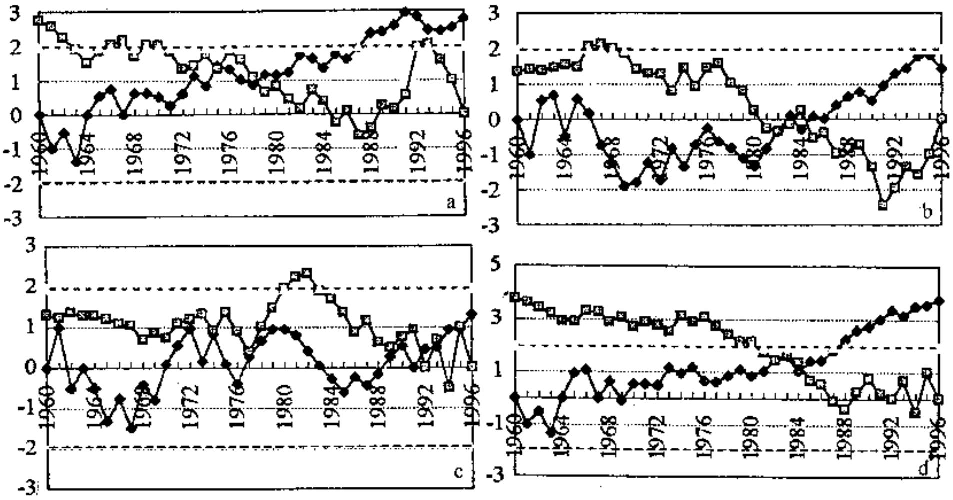

Fig.4 The testing curves of Mann-Kendall method for the monthly minimum temperature of winter in Guangdong . (a) Jan.; (b) Feb.; (c) Dec.; (d) winter –◆– *UF* ; –□– *UB*; – – – line of confidence

Next is the result analyzing the minimum air temperature:

In January, the *UF* line remains above zero and keeps rising until exceeding the line of confidence in 1987. It is a sign that the minimum air temperature has been increasing since mid-1960's with temperature rise in dominance, being consistent with the linear tendency study. Additionally, the *UF* line intersects with the *UB* line over 1975 ~ 1978. It is then concluded that the minimum air temperature of January in Guangdong since 1964 has been on the side of warming and abrupt changes took place around 1975 ~ 1978.

In February, the *UF* line oscillates around the zero domain in 1960 ~ 1967, indicating insignificant trend of temperature rise or fall. After the year 1971, the *UF* curve is generally on the ascending trend and approaches near the line of confidence in mid-1990's. It is now clear that the period from 1971 up till now is warming. The *UF* line meets the *UB* line in 1982 ~ 1984. Then time around these years is considered to see the appearance of an abrupt change point.

In December, the *UF* line fluctuates near the zero domain, causing ambiguous phase division between temperature rise and fall. A picture of temperature rise more or less on the dominant side in December can still be drawn from the fact that the *UF* line stays above zero most of the time.

For the whole of winter, the *UF* line has been above the zero line and keeps increasing and crosses the line of confidence in late 1980's. During the period, it intersects with the *UB* line in 1982 ~ 1984. It is then drawn that the warming trend has been obvious since mid-1960's for the minimum air temperature in winter Guangdong and this situation abruptly changed in 1982 ~ 1984.

With what is verified for the monthly mean air temperature in DJF in Guangdong (figure omitted), we can now see that the *UF* lines are all within the line of confidence without having significant trend of variation and abrupt changes. In January, the *UF* line varies above zero most of the time with temperature rise in dominance. With reference to the trends of rising and falling of the *UF* line, we roughly determine that the period 1966 ~ 1977 is the phase of cooling and the period 1978 ~ 1996 that of warming. The phase pointer is not obvious for February and December.

A general conclusion, based on the analysis above, is drawn that the trend for the minimum air temperature to warm is quite significant in DJF Guangdong. It is especially supported by the observation that as far as the minimum temperature in January and February has their own turning points in 1975 ~ 1978 and 1982 ~ 1984, respectively; the warming amplitude increases afterwards, which is dominated by positive anomaly. Similar warming trend also exists in the monthly mean air temperature in Guangdong for December and January, but they are much weaker than the monthly minimum temperature.

4.3 *Periodicity*

With the linear trend removed from the maximum entropy mean air temperature series for Guangdong province, we find that its spectral peaks appear every 3.3 and 7.2 years for January, every 2.8 and 4.5 years for February and every 2 and 9 ~ 12 years for December. Studying the maximum spectral entropy of the series of minimum temperature, we discover that the peaks appear near the cycle of 3 years for January, near the cycles of 2.5 years and 9 years for February and near the cycles of 2 years and 9 years for December.

4.4 *Wavelet analysis*

For further recognition of temperature variation in Guangdong on a multi-temporal scale, the MHAT wavelet method is used to study the series of the mean air temperature and minimum air temperature in Guangdong. In the computation, $a = 1, 2, 3, 4, \cdots, 9$.

Fig.5 gives wavelet transformation of the monthly mean temperature and monthly minimum temperature in DJF Guangdong.

As indicated by the figure, the minimum air temperature in January, on the inter-decadal scale, entered into a period of cooling before 1979 and then into one of warming after the year; it was in a period of cooling before 1982 and a period of warming after 1982 for February; it was largely in a period of cooling before 1987 and a period of warming after that, showing a later time of shift.

For the mean temperature, the year 1979 is also the dividing line for cooling and warming periods; there are 5 turning points for February (1963, 1972, 1979, 1987 and 1994) and the years 1964 ~ 1971 and 1980 ~ 1986 were in the periods of cooling and years before 1963, years 1972 ~

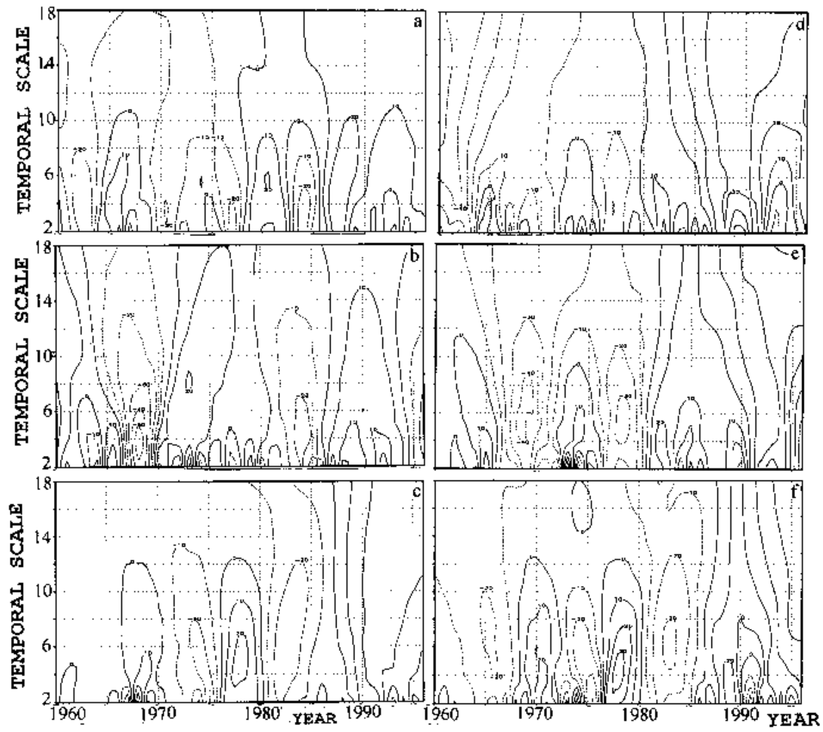

Fig.5 The MHAT wavelet transformation distribution for monthly mean temperature and minimum temperature of winter in Guangdong. (a) Jan. mean; (b) Feb. Mean; (c) Dec. Mean; (d) Jan. min.; (e) Feb. min. (f) Dec. min.

1979 and 1987 ~ 1994 were in the periods of warming. The year 1987 is also the dividing line between cooling and warming for December. The warming period began in 1988.

On the interannual scale (excluding the 2-year scale), the minimum air temperature in winter have only two short spells of warming in the phase of cooling while there is no major spells of cooling in the phase of warming. Cool spells within the cooling period (before 1979) is around 1965 and 1972 ~ 1975 for January, 1963 ~ 1966 and 1972 ~ 1976 for February and 1968 ~ 1972 and 1977 ~ 1980 for December.

For mean temperature, there are five turning points for January (1964,1968,1978,1982 and 1985) and cooling and warming phases appear alternatively, in 1960 ~ 1963, 1969 ~ 1978 and 1983 ~ 1985 for the cooling phase, and 1964 ~ 1968, 1979 ~ 1982 and 1986 ~ 1996 for the warming period; there are also five turning points for February, which has generally the same trends of cooling and warming changes on both inter-decadal and interannual scales and has similar time of appearance; there are three turning points for December (1976, 1980 and 1988), with the cooling phases over 1960 ~ 1976, 1981 ~ 1988 and the warming phases over 1977 ~ 1980 and 1989 ~ 1996.

In general, the wavelet analysis gives us detailed structure of mean and minimum air temperature in DJF months in Guangdong on the scales mentioned above and diagnosis of turning points on respective scales. Studying from the amplitude of wavelet transformation, February has the largest amplitude of variation in temperature, suggesting that the air temperature is the most unstable in the month.

5 DISCUSSIONS ABOUT WINTER TEMPERATURE IN GUANGDONG

Summing up what we have done in the previous sections, we can now know that over the recent 37 years across the entire province, the air temperature tends to rise with mild effects while the minimum air temperature has a much large increase. Of them the linear warming trends are the most significant for the mean minimum temperature in January and the whole winter season. Some results (Zai and Ren, 1997) have revealed a smaller extent of warming in the south of China than in the northeastern and western parts of China.

On the inter-decadal scale, the winter temperature in Guangdong agrees well with the fact that widespread warming over the past 40 years appears across the globe and there is a rise of 0.3°C in mean temperature over 1951 ~ 1990 in China. The one during wintertime notably marks the temperature ascent since early 1970's in China. The rise in the minimum temperature in Guangdong began in the latter half of the 1960's and it has been more significant since the 1980's, making the province well inside a warming spell.

Two factors are considered to have caused the global warming, one is anthropologic and the other natural. Some work (Jiang and Ding, 1996; Wu and Zhang, 1996) point out that in the three warming events taking place over the past 100 years, the first (end of 19th century) may have been resulted from relatively inactive volcano activity; the second (1920's ~ 1930's) may have been linked with weakening effects of volcanoes in company with strengthened solar activity; the third (since the 1970's) may have been the consequence of green house effects. The growth of urban population, the increase of green house gases as a result of discharge by transportation vehicles and the development of industrialization have all strengthened the heat-island and green house effects in cities. Studying the results for Guangzhou (Huang, Liang and Wu, 1994), we know that the city is also facing with the problem of heat-island. Generally speaking, the heat-island effect is the strongest in December and January in Guangzhou. It is conceivable that the heat-island effect may well attribute to the fact that warming is more significant in wither than in summer as well as that climate in Guangdong has become warmer. In Guangzhou, the heat-island effects are diurnally shown, being stronger during the nighttime. The green house effect is shown quite differently in day and night due to the geographic location of Guangzhou in the southern subtropical zone. It weakens much of the direct solar radiation during the day but reduces much of the heat loss through potential long wave. The minimum air temperature usually occurs in the night and the green house effect may lead to larger rise in minimum temperature than in mean temperature. It is, therefore, not negligible that the urbanization and green house effect may play a role in winter warming in Guangdong.

In addition, it must also be noted that the anomalies of atmospheric circulation may have affected these natural processes. From our preliminary study, we conclude that the cold air surge has been hitting Guangdong (by the standard that one or more observation station in the province meet the respective criteria) by a decreasing density: the annual number is 3.6 processes of cold surge in the 1960's, 2.2 in the 1970's and 1.6 in the 1980's. It is doubtless to say that the sustained decrease of cold surge attacks as they are will eventually cause sustained warming of winter temperature, especially the minimum temperature in Guangdong. It is generally the case that air temperature usually remains at a high level just prior to the arrival of cold air surge and it rapidly drops with the passage of the surge. It is why the cold surge has a much weaker effect on mean temperature than on minimum temperature. The decreasing number of cold air surge hits may be the key factor in governing the rate of warming in Guangdong because it not only affects the temperature change on the inter-annual scale but also on the inter-decadal scale. Conclusions drawn above are presented for further discussions on the winter warming in Guangdong and more work has to be done to arrive at a more definite conclusion in this respect.

6 CONCLUDING REMARKS

a. The air temperature shows a tendency to increase in Guangdong and it is particularly so with the minimum temperature. It rose by an extent larger than the mean air temperature and abrupt changes occurred in 1975 ~ 1978 and 1982 ~ 1984 for January and February. The amplitude of temperature ascent is dramatically larger after the change. The minimum air temperature began rising in late 1960's and with a larger extent when it came to the 1980's and Guangdong can be said to enter a phase of warming.

b. With the method of maximum entropy spectrum, the variation of minimum air temperature in Guangdong is found to have cycles of 2 ~ 3 years and about 10 years.

c. As what is revealed with the wavelet analysis, the variation of winter temperature in Guangdong is marked with multiple temporal scales. On inter-decadal scale, the minimum and mean temperature in January, February and December in Guangdong began their respective spells of warming in 1979, 1982 and 1987 (with the exception of February in the case of mean air temperature). On the interannual scale, a number of cooling and warming phases are identified, in which the warming of temperature is relatively smooth in January but by a larger extent and in a more complicated way in February.

d. The urban heat-island and green house effects may be among the causes for the winter warming in Guangdong and the sustained decrease in the number of cold air surge attacks may be the deciding factor for it.

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