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VARIATION AND CAUSES OF PERSISTENT DROUGHT EVENTS IN GUANGDONG PROVINCE

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Abstract: Variation characteristics of persistent drought events in Guangdong province are analyzed using 45-year (1961–2005) and 86-station observational precipitation data of Guangdong, and the causes of drought events are discussed from different angles (e.g., atmospheric circulation, sea surface temperature) on the basis of global coverage datasets of sea surface temperature and atmospheric elements. It is found that the occurrence frequency of persistent drought events in Guangdong province is once every 26 months on average, and autumn-winter or winter-spring persistent drought events take up the majority. The persistent drought events possess large scale spatial characteristics. While the 1960s is the most frequent and strongest decade of drought events in the latter half of the 20th century, the occurrence is more frequent and the intensity is stronger in the first five years of the 21st century (2001–2005). This reflects the response of regional extreme climatic events in Guangdong to global climatic change. The atmospheric circulation, sea surface temperature, etc, appear to have different abnormal characteristics when drought events happen in different seasons. The results of this paper provide some good reference information for the drought forecast, especially for the dynamic interpretation of climatic model products.

Key words: persistent drought events; variation characteristics; causes; Guangdong province

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1 INTRODUCTION

Droughts are one of the main natural disasters in China, resulting in profound destruction with each of their major outbreaks in history. Although rainfall is abundant in Guangdong—with the annual amount being as much as 1780 mm—seasonal shifts are distinct between dry and wet spans, and localized and seasonal droughts are quite frequent due to uneven distribution across different time of the year and different parts of the province. As the provincial rainfall for the rainy season (April to September) takes up 70% to 85% of the yearly total, research efforts are focused more on the annually first raining period (April to June) and the annually second raining period (July to September)[1-7] than on the other time of the year[8]. In Guangdong, spring and autumn are the two agricultural seasons for twice-annually paddy rice and dry-land crops, which require plentiful supply of water. It cannot be neglected that spring and autumn droughts are two possible conditions posing threats to these crops. In China, research on droughts is conducted mainly for the northern part of the country where rainfall is relatively little[9-12] while just some preliminary understanding has been gained of the droughts occurring in Guangdong, a province in the south. Based on observed conditions of droughts for rice growth in the province, criteria are designed for assessment of the drought conditions for paddy rice growth as well as the general conditions of droughts, patterns of drought evolution are analyzed, and measures for working against droughts are suggested (Song et al.[13]). Preliminary classification has been done of the destruction brought about by droughts in the spring and autumn in Guangdong[14]. As little has been done on the provincial persistent droughts, it is necessary to have further understanding of how and why the droughts occur so as to provide climatic background for drought prediction. In this work, surface observations from 86 stations across the province, global monthly mean Extended Reconstructed Sea Surface Temperature (ERSST) and global multiple atmospheric elements from National Centers for Environmental Protection/National Center

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for Atmospheric Research (NCEP/NCAR, USA) are used to analyze the temporal and spatial variations of the persistent drought events in Guangdong, discuss the background of atmospheric circulation and external signals of SST for the events and examine their causation from a new point of view (differences between sea and air temperatures).

2 DATA AND METHODS

2.1 *Data*

Covering the period from January 1961 to December 2005, the data used in this work include (1) monthly precipitation data from 86 surface observation stations in the province (provided by the Climate Center, Guangdong Meteorological Bureau), (2) ERSST[15], which has a horizontal resolution of 2°×2° (extracted from a NOAA website[1]), and (3) monthly mean data of global 2.5°×2.5° atmospheric elements (wind speed, air pressure, geopotential height and air temperature) from NCEP/NCAR[16].

2.2 *Persistent drought events and their definition*

A persistent drought event is defined to take place in Guangdong if percentages of mean rainfall anomalies are less than −10% for three months or more in a row, percentages of accumulative rainfall anomalies are less than −200%, and percentages of monthly mean rainfall anomalies are less than −30%. The intensity of the persistent drought event is expressed by the percentage of accumulative rainfall anomalies. To study interdecadal variations conveniently, the sum of the accumulative anomalies for all of the events in the decades is used in this work to characterize the intensity of persistent droughts in various decades.

3 TEMPORAL AND SPATIAL VARIATIONS OF PERSISTENT DROUGHT EVENTS

A total of 21 persistent drought events occurred from January 1961 to December 2005, or once every 26 months on average. Table 1 presents the time of occurrence, number of persisting months and percentages of accumulative anomalies of these drought events. It shows that there are seven autumn-to-winter drought events, five winter-to-spring drought events, four summer-autumn-winter drought events, two winter-spring-summer drought events and two autumn-winter-spring drought events, in addition to one persistent drought that continues across two years. It is clear that autumn-to-winter and winter-to-spring droughts are the main forms of persistent events in the province. Though it is possible for these events to include the spring (March to May), the season is the only one that does not start off a drought. In other words, it is highly unlikely for a persistent drought to begin in spring unless it follows one that starts from the preceding winter, which is useful to some degree for the prediction of sustained drought events. Usually, drought events last for three to seven months in Guangdong, with most of them appearing in two consecutive seasons (13 times), some of them in three consecutive seasons (7 times) and one in 13 months (from July 1998 to July 1999). For the intensity, a drought that lasted for seven months in the winter, spring and summer of 1962 to 1963 is the strongest event for the 45 years of interest, which features a percentage of −463% for the accumulative precipitation anomalies. 1998−1999 and 2004−2005 are the other two drought events that follow in intensity.

Table 1. Time of occurrence, number of persisting months, percentages of accumulative anomalies and percentages of monthly mean rainfall anomalies of the 21 drought events.

Ser. No.	Start time	Covering seasons and duration (Number of month)	Percentages of accumulative rainfall anomalies (%)	Percentages of monthly mean rainfall anomalies (%)
1	Jan.1962	Win.Spr.(4)	−218	−54
2	Dec.1962	Win.Spr.Sum.(7)	−463	−66
3	Nov.1964	Aut.Win.Spr.(5)	−315	−63
4	Aug.1966	Sum.Aut.Win.(6)	−265	−44
5	Sept.1967	Aut.Win.(5)	−252	−50
6	Aug.1969	Sum.Aut.Win.(5)	−254	−50
7	Jan.1971	Win.Spr.(5)	−229	−45
8	Dec.1973	Win.Spr.(4)	−245	−61
9	Feb.1977	Win.Spr.(3)	−225	−75
10	Jan.1979	Aut.Win.(4)	−299	−74
11	Aug.1980	Sum.Aut.Win.(7)	−326	−46
12	Nov.1983	Aut.Win.Spr.(5)	−316	−63
13	Jan.1985	Aut.Win.(4)	−278	−69
14	Jun.1989	Sum.Aut.(6)	−282	−47
15	Feb.1991	Win.Spr.(4)	−210	−52
16	Jan.1996	Aut.Win.(3)	−248	−82
17	Jul.1998	Years(13)	−427	−32
18	Jan.2002	Win.Spr.Sum.(6)	−243	−40
19	Jan.2003	Aut.Win.(3)	−226	−75
20	Aug.2004	Sum.Aut.Win.(7)	−393	−56
21	Jan.2005	Aut.Win.(3)	−208	−69

Note: Spr.: spring; Sum.: summer; Aut.: autumn; Win.: winter.

Figure 1 gives the distribution of percentage for mean rainfall anomalies made from composites from 21 of the province's persistent drought events. It shows that these events are present across the whole province, being −200% to −300% in most locations but more than −300% in the coastal area around the estuary of Pearl River. For individual events, however, the percentages vary in spatial distribution; they are

[1] ftp://ftp.ncdc.noaa.gov/pub/data/ersst- v2/

generally negative across the province but positive at a small number of stations for just a few events (figure omitted). In other words, the persistent drought events defined in this work are actually provincial over extensive stretch of area.

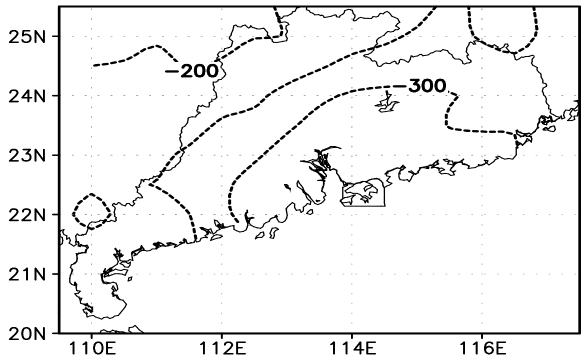


Figure 1. Percentages of mean rainfall anomalies made from composites of the 21 persistent drought events.

Figure 2 presents the multi-year variation of the percentages of monthly mean rainfall anomalies in Guangdong; persistent droughts occurred six, five, three and three times in the 1960s, 1970s, 1980s and 1990s, respectively, making the 1960s a decade of the most frequent droughts in the four decades. It is noteworthy that four drought events have already taken place in the first half of the 2000s, i.e., the probability is 4/5, larger than that of the 1960s as a whole (3/5). With regard to the intensity, the 1960s, 1970s, 1980s, and 1990s are −1767, −998, −1202, and −885, respectively, making the 1960s a decade that has the strongest persistent drought events. In comparison, the sum of the percentages is already −1070 for the first five years of the 2000s, more than half of that of the 1960s. For either the frequency or the intensity, the droughts in the last few years are shown to be quite serious, which reflect the responses of extreme climatic events of Guangdong to global climate change.

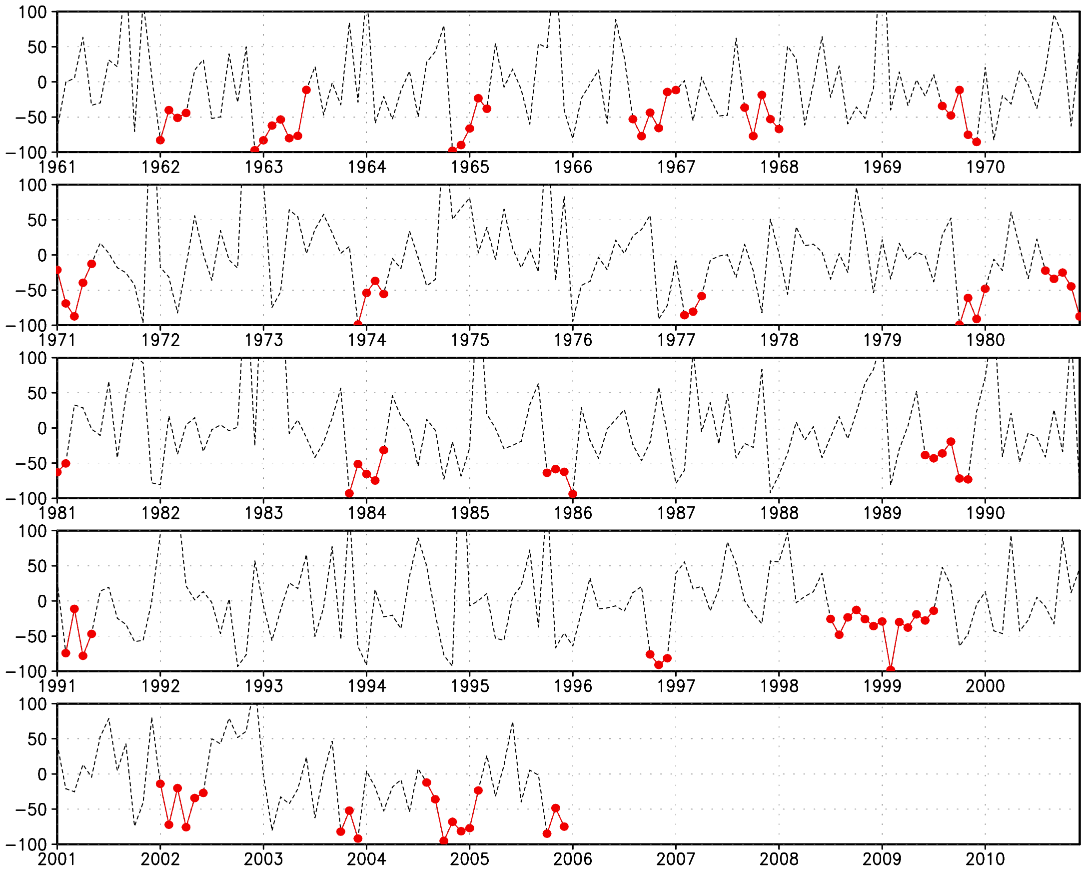


Figure 2. Multi-year variations of the percentages of monthly mean rainfall anomalies in Guangdong. The bold lines stand for the process of the drought event and the abscissa is for the year.

4 ATMOSPHERIC CIRCULATION

Located in a monsoon region well-known globally, Asia is marked with distinctive season changes in the atmospheric circulation. As differences are substantial in the circulation background of drought events in different seasons, it is necessary to discuss the anomalies of the atmospheric circulation in spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).

4.1 *Spring*

Figure 3a gives the composite distribution of sea surface pressure for spring droughts. As compared to the climatological mean (Figure 3b), the Aleutian low in North Pacific is weaker and its center is more westward while the center of the subtropical high in the Pacific is more northward and stronger. Therefore, on a composite chart that shows the sea surface pressure anomalies, the spring drought is associated with positive anomalies in the mid- and higher-latitudes of the Pacific but negative anomalies in the tropics. The distribution is similar to North Pacific Oscillation (NPO) but with a more southward location of the anomalous center. The south of China is with negative anomalies of sea surface pressure, indicating the presence of weaker cold air.

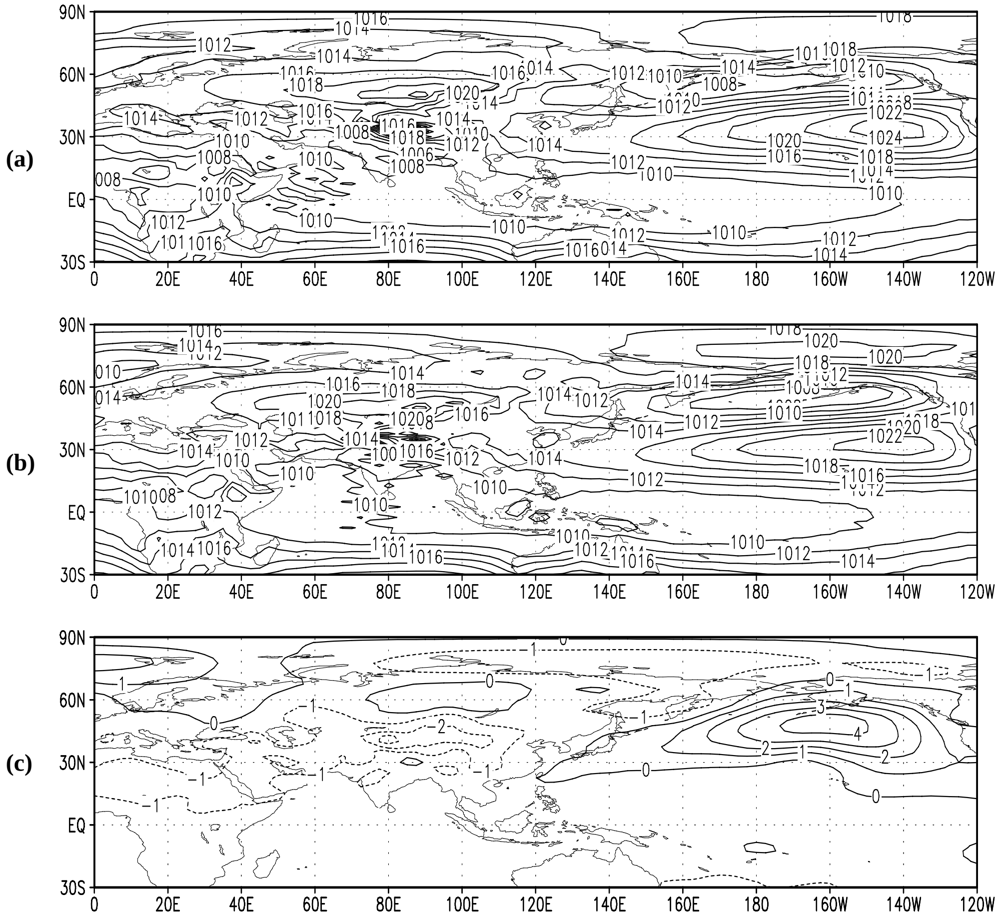


Figure 3. Distribution of composite sea level pressure. a: distribution of composite droughts in the spring; b: climatological mean for the spring; c: distribution of sea level pressure for spring droughts.

For spring droughts, circulation anomalies at 850 hPa in the lower troposphere are characterized by easterly anomalies in the equatorial Indian Ocean and central and eastern Pacific and anti-cyclonic anomalies in North Pacific, suggesting the presence of a stronger subtropical high (Figure 4a, only anomalies are given due to the limitation of text). Southerly anomalies are in the mid- and lower-latitudes of the East Asian continent. Such variation of low-level tropospheric circulation is associated with the change in surface pressure. It further shows that weaker cold air, lack of cold air activity in the south of China and more northward location of an area where the north and south airflow converge are the factors leading to dry and less rainy weather in the spring. It also supports the scientific reason behind a Chinese folk proverb that goes: spring chill brings about rains.

At the geopotential height of 500 hPa in the mid-tropospheric layer (Figure 5a), the heights of isobaric surfaces are increasing from North Pacific to the southeastern China while decreasing over the mid- and higher-latitudes of Eurasia, suggesting the presence of a shallower main trough in East Asia. It is well consistent with lower tropospheric circulation and sea surface pressure, indicating that cold air is weaker in the south of China in association with spring droughts in Guangdong.

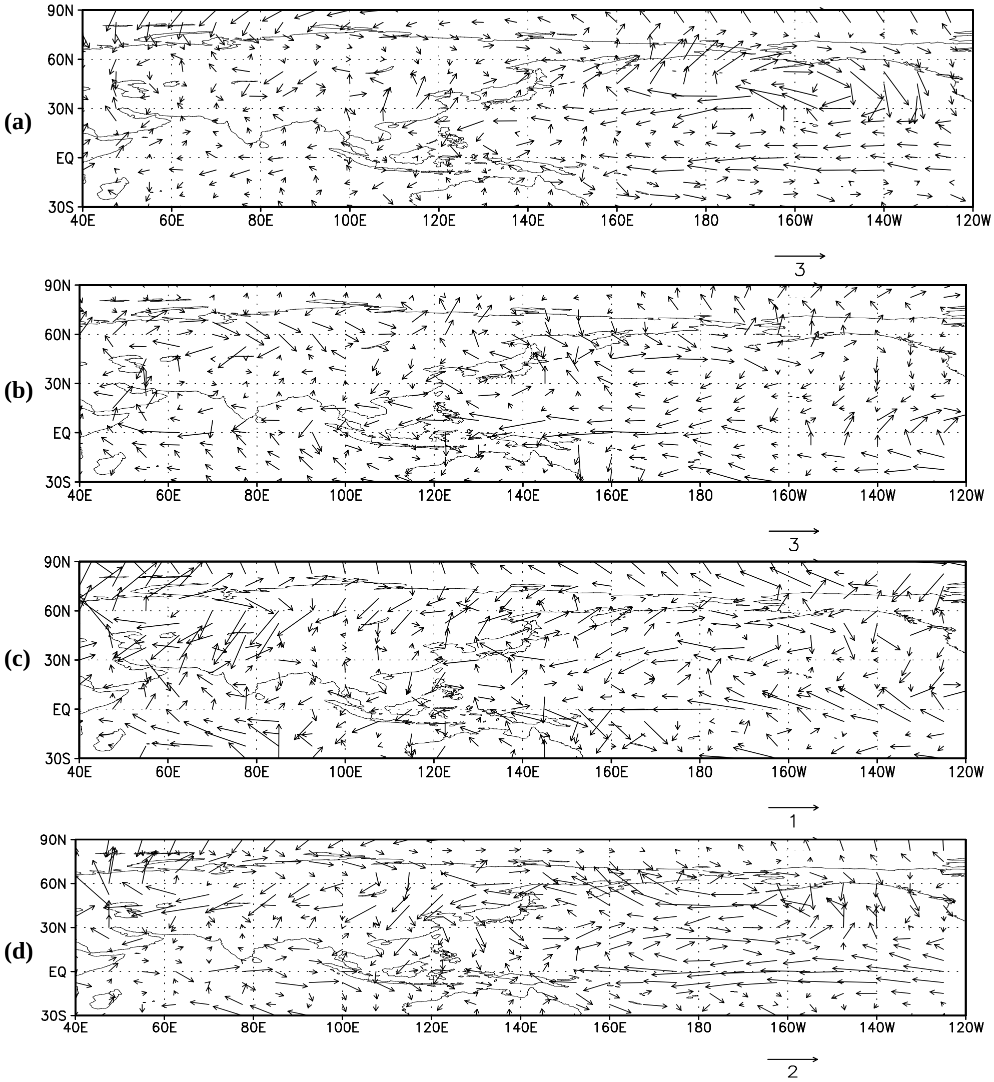
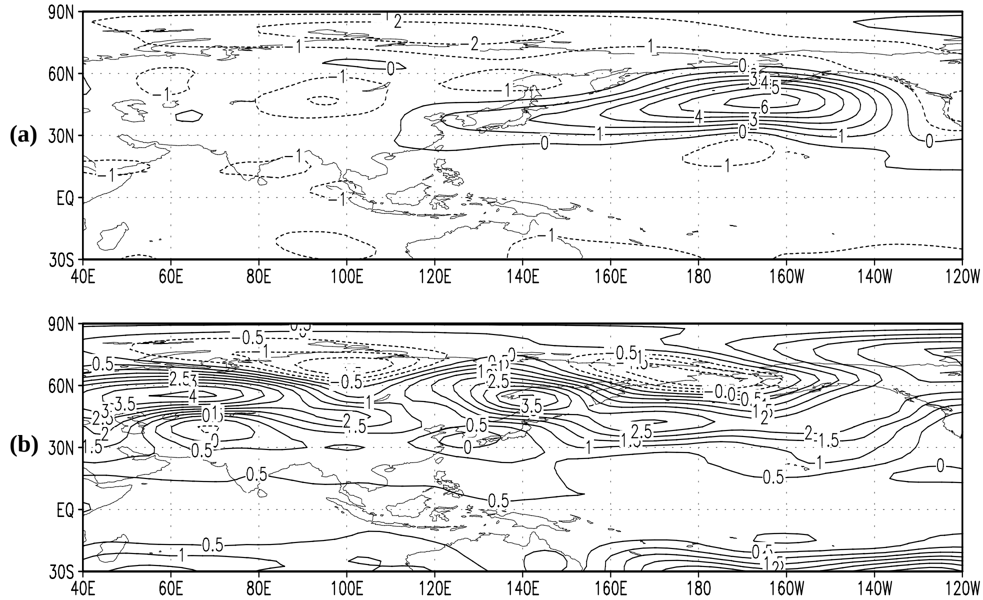


Figure 4. Anomalies of 850 hPa winds for droughts in Guangdong in different seasons. a: spring; b: summer; c: autumn; d: winter.



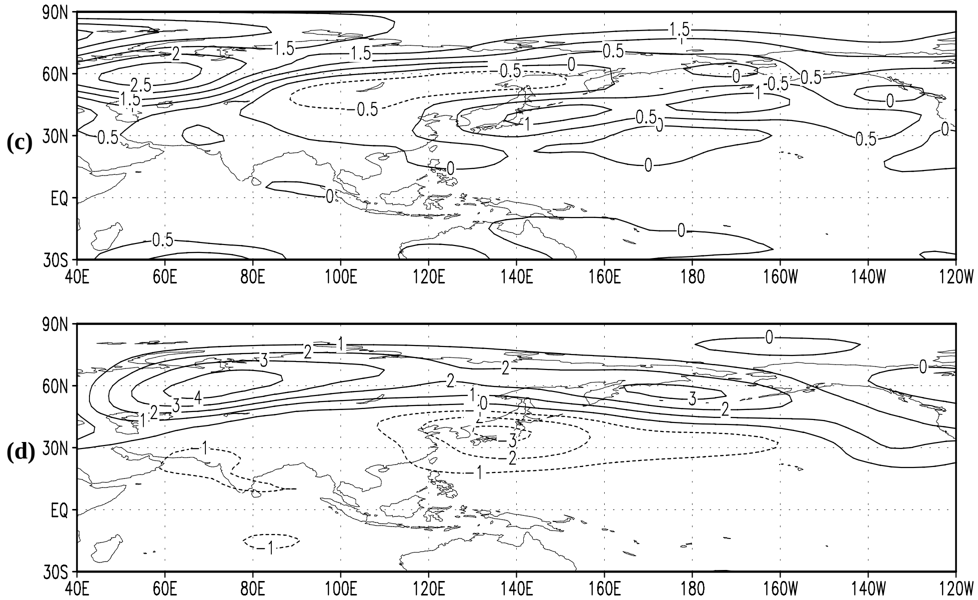


Figure 5. Geopotential heights at 500 hPa for droughts in Guangdong in different seasons. Other captions are the same as those in Figure 4.

4.2 *Summer*

For the background of summer climate (Figure 6b), the sea surface pressure is low over the Asian continent but high over the mid- and lower-latitudes of the Pacific. When droughts occur in summer, sea surface pressures are distributed like the climatological mean (Figure 6a) though with some changes in both the continental low and the subtropical high in the Pacific. It is shown more clearly by the anomalies (Figure 6c). When droughts hit Guangdong in summer, low pressures weaken over the Asian continent while the subtropical high intensifies over the Pacific. On the map of anomalous 850 hPa circulation at the lower troposphere (Figure 4b), there is easterly anomaly in the northern Indian Ocean-Bay of Bengal-South China Sea-western Pacific and northeasterly anomaly in the mid- and lower-latitudes of the East Asian continent, suggesting the presence of a weak summer monsoon. It is then known that the summer drought in Guangdong is related to a weak summer monsoon. For the 500 hPa geopotential height field at the mid-troposphere (Figure 5b), the heights of isobaric surfaces are decreasing in Lake Baikal and areas north of 60°N in North Pacific but increasing in other areas, suggesting the presence of a strong trough over Baikal and a strong mid-ocean trough over North Pacific. In summer, the westerlies are located more northward so that the subtropical high in the western Pacific is closely linked to the weather and climate in China. In association with summer droughts in Guangdong, the subtropical high in the western Pacific is much stronger and covers a larger area, with its westernmost point of the ridge being more westward.

4.3 *Autumn*

Autumn is a season in which the atmospheric circulation adjusts itself. For the seasonal mean (Figure 7b), the Asian continent is generally dominated by high pressures, the Aleutian low forms at relatively northward locations and the subtropical high is still active over quite an extensive area. With autumn droughts, high pressures are weak over the East Asian continent while the subtropical high and Aleutian low are northward (Figure 7a). It shows that the years with autumn droughts are linked with slow adjustment of sea level pressure and inactive cold air. For the anomalies of sea level pressure (Figure 7c), the amplitude of variations of sea level pressure is smaller than that of other seasons. For the 850 hPa flow field in the lower troposphere (Figure 4c), the autumn drought is associated with southerly and northerly anomalies in the north and south respectively, turning it into a region with anomalous divergence. For the geopotential height anomalies in the middle troposphere (500 hPa), a pattern of Eurasian-Pacific Ocean (EUP) teleconnection is shown where Europe, Asia and the Pacific Ocean are positive, negative and positive, respectively, and the wavetrain of the teleconnection is northwest-southeast oriented. The positive anomalies in the western North Pacific and negative anomalies in East Asia suggest a weak and westward main trough in the latter area.

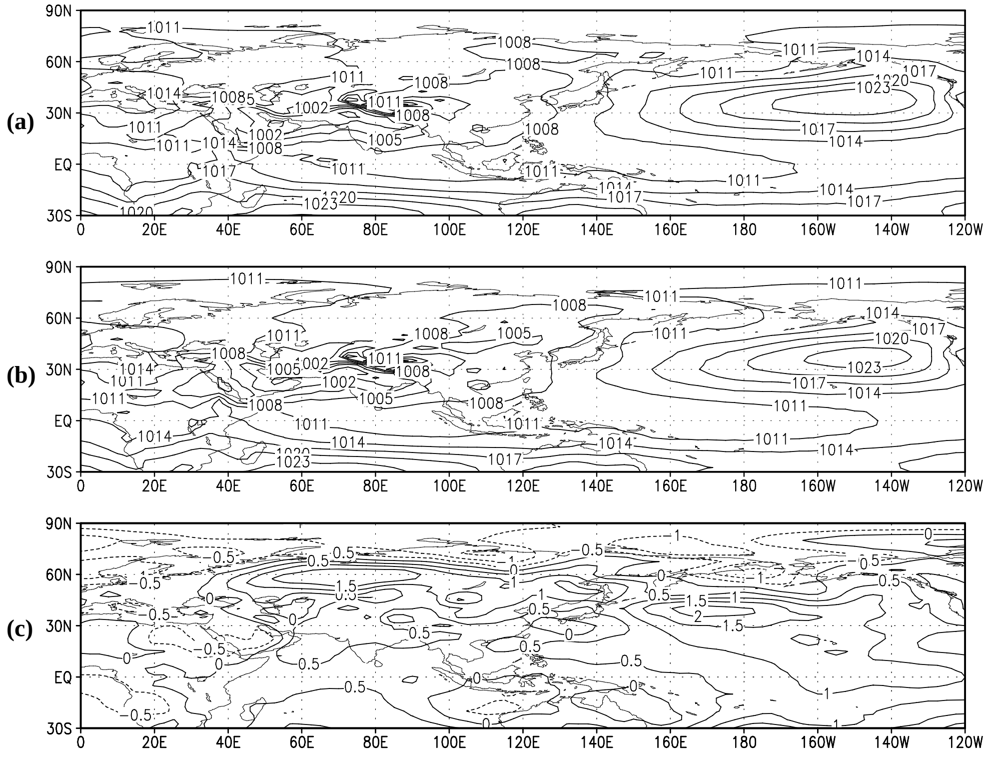


Figure 6. Same as Figure 3 but for the summer.

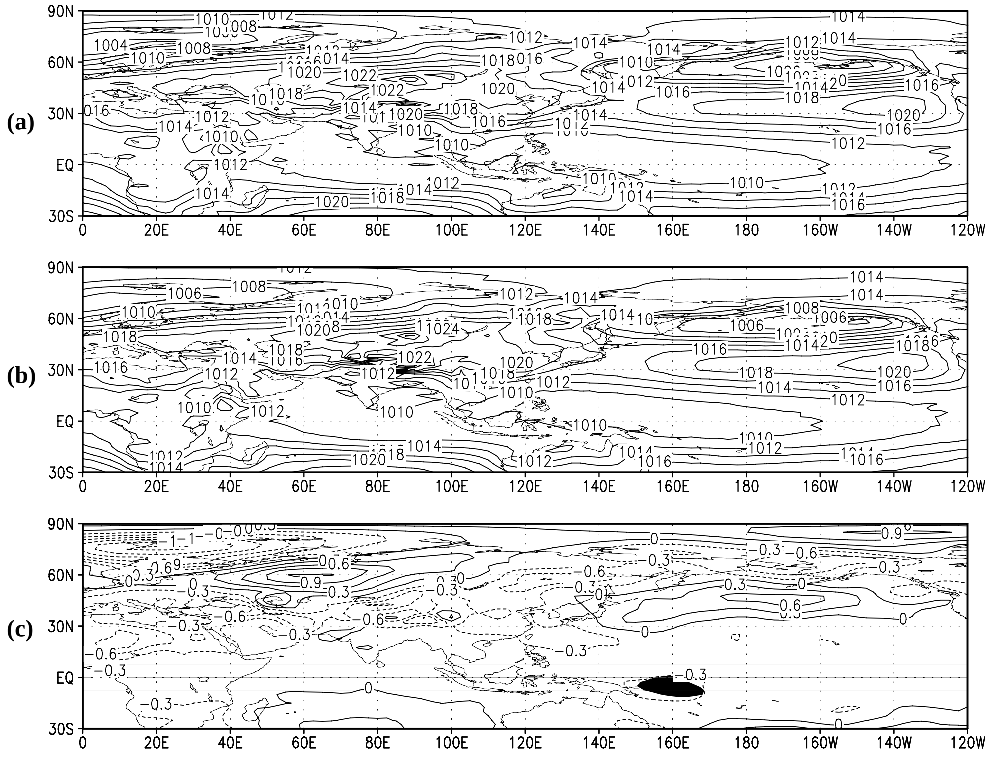


Figure 7. Same as Figure 3 but for the autumn.

4.4 *Winter*

The sea surface pressure anomalies are extensive for the winter drought (Figure 8), with (1) a strong Siberian high (also known as Mongolia high), (2) a weak subtropical high and Aleutian low in North Pacific, and (3) a weak subtropical high in North Atlantic and a weak Icelandic low. As a result, sea surface pressures are positively anomalous over the mid- and higher-latitudes of the Eurasian continent while the northern parts of North Pacific and Atlantic are positive and the southern parts of them are negative, showing North Pacific Oscillation (NPO) and North Atlantic Oscillation (NAO), two typical patterns of teleconnection. Li[17] showed that the probability is slight for both NPO and NAO to appear simultaneously. With the winter drought, significant peculiarity is found in the teleconnection patterns of sea level pressure, i.e., NPO and NAO appear at the same time. In other words, such peculiarity is also a good indicator that droughts will take place in the winter of the province.

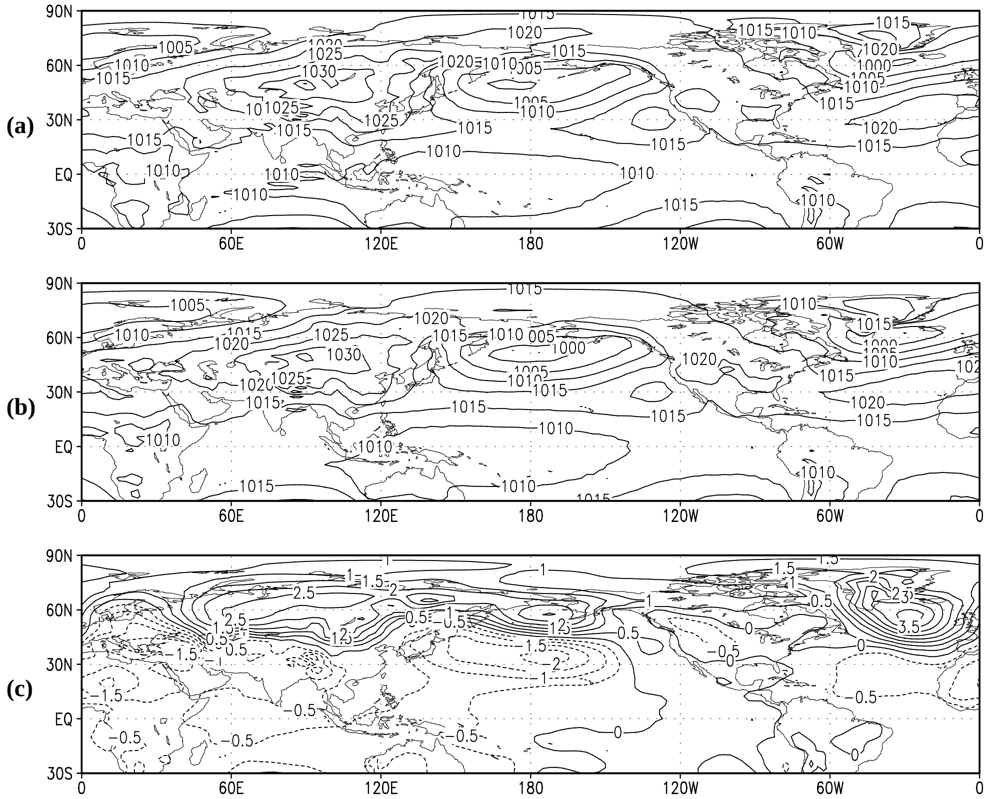


Figure 8. Same as Figure 3 but for the winter.

For the 850 hPa circulation anomalies in the lower troposphere (Figure 4d), northerly anomalies are present over extensive parts of the East Asian continent and South China Sea, consistent with the variation of surface pressures. It further suggests a strong Siberian high, intensive activity of cold air over East Asia and lack of convergence between cold and warm air over the south of China, resulting in dry and less rain weather in winter.

For the 500 hPa geopotential heights in the middle troposphere (Figure 5d), the heights of isobaric surfaces are increasing over the mid- and higher-latitudes of the Eurasian continent while decreasing over the coast of the mid- and lower-latitudes of East Asia. It suggests a strong Siberian high ridge and a strong East Asian trough in the mid- and lower-latitudes. The situation is highly consistent with the lower tropospheric flow field and sea surface pressure field, indicating strong activity of cold air over the low latitudes of China. It is also noteworthy that there is a pair of northeast-southwest dipoles in the western North Pacific, which is distributed in a way similar to the pattern of western Pacific (WP) teleconnection, while a typical WP pattern is generally north-south oriented[17]. For this reason, the northeast-southwest dipole pair as presented in Figure 5d is called a quasi-WP teleconnection pattern (denoted as QWP). Corresponding to the NPO for the sea level pressure, QWP differs in that the vertical axis of the subtropical anomalous center inclines to the west with height.

In summary, some degrees of differences or even opposite features exist in the circulation anomalies for different seasons. Take winter for example. Strong activity of cold air (or strong winter monsoon) will cause droughts in Guangdong while spring droughts are linked with weak activity of cold air. It is attributable to the seasonal change of the atmospheric circulation. During the winter when northerly winds prevail, strong cold air results in strengthened northerly winds in the south of China and lack of convergence between the south and north airflows, giving rise to droughts. Spring is a season when winter circulation transforms to summer circulation and the background circulation changes to southerlies over the low-latitudes in the region. If no cold air is advancing south, the region will also receive less rain due to the lack of conditions for airflows to converge.

5 SEA SURFACE TEMPERATURE AND

AIR-SEA TEMPERATURE CONTRAST

With spring droughts, simultaneous (positive) changes in sea surface temperature are significant in North Pacific (Figure 9a) and changes in negative anomalies are also quite considerable in the equatorial eastern Pacific. For the summer drought, the simultaneous changes in sea surface temperature are characterized by negative anomalies in the equatorial central and eastern Pacific and positive anomalies in the western North Pacific (Figure 9b). For the autumn drought, they are marked by negative anomalies in the equatorial eastern Pacific (east of 140° W) and positive anomalies in North Pacific (Figure 9c). For the winter drought, negative anomalies are over the equatorial central and eastern Pacific and positive anomalies are over the western North Pacific, a typical pattern of significant La Niña (Figure 9d). Negative anomalies are over the tropical Indian Ocean and South China Sea. As shown in comparisons, each of the seasonal droughts in Guangdong is linked with negative anomalies of the sea surface temperature in the equatorial eastern Pacific, though with differences in the intensity and coverage of the anomalies. During winter and summer, the negative anomalies are both intense and extensive, covering mainly the Niño3 and Niño4 zones during summer and a westward located anomalous center (150°W). During winter, the negative anomalies are all over Niño1–4 with an eastward located anomalous center (120°W). During the transitory seasons (spring and autumn), the drought is associated with anomalously weak sea surface temperatures in the equatorial eastern Pacific and relatively strong positive anomalies in the western North Pacific. It shows that the external forcing signals vary depending on the season.

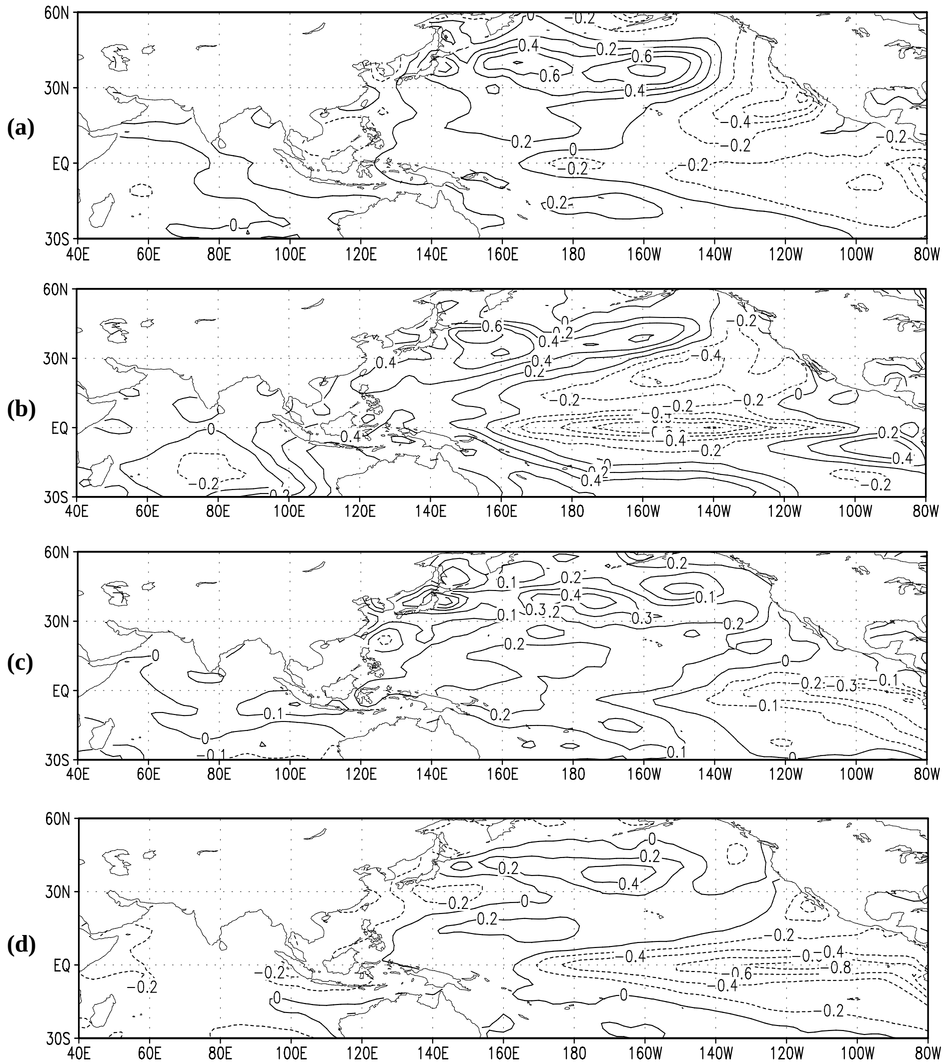


Figure 9. Anomalous field of sea surface temperatures for the drought in different seasons of Guangdong.

As shown in Sun et al.[18] and Cheng and Wu[19], air-sea temperature contrasts have some effects on the transport of heat from the ocean and atmosphere and the conveyance of momentum as well as on such weather as land-sea breezes and sea fog in the coastal area[20]. The air-sea temperature contrasts are significantly related to the intensity of convection in the area of South China Sea monsoon in winter (the Indian Ocean), spring (the tropical central Pacific), winter (the South China Sea-western Pacific)[21]. It is clear that the air-sea temperature contrasts are one of the important physical quantities. It is then our attempt in this work to associate it with the drought in Guangdong, which shows that they are well linked. Figure 10 gives the composite anomalies of air-sea temperature contrasts (with sea temperature minus air temperature) for the winter drought. It shows that waters off the coast of East Asia, western Pacific and South China Sea are covered by positive anomalies while the sea surface temperature there is negatively anomalous with the winter drought (Figure 9d). It can then be inferred that the sea surface temperature is negatively anomalous in a more significant way. In other words, the cold air is relatively strong, which is completely consistent with the result presented above. It is then known that the anomalous variation of the air-sea temperature contrast with the winter drought may result from the effect of the atmosphere on the ocean. More study is deserved on the lagging effect of the anomalous variation of the air-sea temperature contrast on weather and climate.

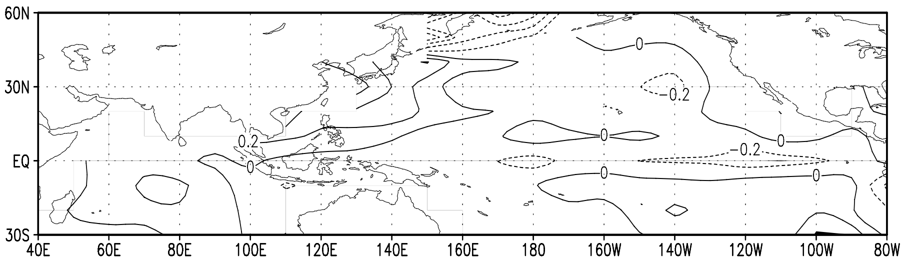


Figure 10. Anomalous composites of air-sea temperature differences (sea temperature minus air temperature) for the winter drought in Guangdong.

6 CONCLUDING REMARKS AND DISCUSSION

(1) In Guangdong, persistent droughts are widespread across the province at a rate of once every 26 months over the past 45 years. They mainly occur in the autumn/winter or winter/spring, taking up 12/21. The 1960s are a decade with frequent appearances but the period 2001–2005 has surpassed it with a rate of 3/5, reflecting the response of extreme climate events in the region of Guangdong to global climate change.

(2) Due to significant seasonal changes in the atmospheric circulation in the East Asian monsoon region, different features are shown in its anomalous variation for different seasons with the drought. The spring drought is closely linked with weak cold air in the south of China and the NPO teleconnection pattern in the sea surface pressure of North Pacific. With the summer drought, the summer monsoon is weak and the western Pacific subtropical high is significantly strong and a 500 hPa trough over Lake Baikal and a mid-oceanic trough are powerful. With the autumn drought, a high is weak at the sea surface level, and 850 hPa southerly and northerly anomalies are located in northern and southern Guangdong, respectively, and a main 500 hPa trough is weak and located westward. The winter drought is associated with strong winter monsoon and the NPO and NAO teleconnection patterns occurring at the same time. Compared with the other seasons, the winter is significant in both the intensity and area of the anomalies of the atmospheric circulation when droughts take place in the province, suggesting that the background circulation for the drought is characterized by large-scale or even planetary scale features.

(3) The external signals for the drought vary with season. For the winter and summer drought, concurrent sea surface anomalies are mainly negatively anomalous in the equatorial central and eastern Pacific. For the spring and autumn drought, they are more significant in North Pacific. The winter drought is with a well-defined pattern of La Niña distribution. As shown in Zhang et al.[22] and Wang et al.[23], during the mature phase of El Niño (La Niña), anti-cyclonic (cyclonic) circulation anomalies are formed over the South China Sea and western Pacific, making the low-latitude East Asian region, which is to the northwest of the anti-cyclonic (cyclonic) circulation anomalies, in the control of southerly (northerly) anomalies. This finding is consistent with the result presented above that the winter drought in Guangdong is linked with strong winter monsoon. It is then clear that sea surface temperature anomalies affect local weather and climate via the atmospheric circulation anomalies.

In this work, a systematic study has been conducted on the temporal and spatial variation of persistent drought events in Guangdong and their causation has been discussed from a number of angles in order to provide good reference for the prediction of droughts (especially dynamic interpretation using the products of climate models).

Our another paper[24] addresses the patterns of anomalous sea surface temperatures related to these events and their processes of influence.

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