STUDIES ON CLIMATE CHANGE IN CHINA IN RECENT 45 YEARS

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ABSTRACT

Based on the data of monthly mean air temperature and precipitation from about 400 stations in 1951—1995, and the data of maximum and minimum air temperatures, relative humidity, total cloud cover and low-cloud cover, sunshine duration, evaporation, wind speed, snow-covered days and depth, and soil temperatures in 8 layers from 0 m down to 3.2 m from 200 odd stations in 1961—1995, the climate change and its characteristics in China in recent 45 years have been analyzed and studied comprehensively. This paper, as the first part of the work, has analyzed the climate change and regularities of such meteorological elements as mean air temperature, maximum and minimum air temperatures, precipitation, relative humidity and sunshine duration. The possible mechanism on climate change in China and the climate change and regularities of other meteorological elements will be discussed in another paper as the second part.

Key words: climate change in China, air temperature and precipitation, maximum and minimum air temperatures, relative humidity and sunshine

I. INTRODUCTION

Since 1980s, Chinese climatologists have paid much attention to studies on the modern climate change in China and its regularities. Zhang et al. (1982) studied the variation in grades of air temperature and precipitation in China in this century before 1980 by use of the graded data of both elements, and found that since 1900 China has its warmest air temperature in the 1940s, afterwards the air temperature decreases, the 1970s has its air temperature lower than the 1940s. The climate in China tends to be arid since the 1950s. Subsequently, Tu (1984), Zhao et al. (1989) and Lin et al. (1990) made further studies on the variation of air temperature and precipitation. Chen et al. (1991; 1992; 1994; 1995) have made a series of studies on the same topic in China in recent 70 years, and indicated that even though the 1980s is included in consideration, the air temperature in China remains to be warmest in the 1940s, and precipitation ranks first in the 1950s. Since late 1970s, the air temperature has increased obviously. They clearly pointed out that the warming region in China is mainly in the area north of 35°N, and a cooling region exists in area south of 35°N and east of 100°E, and that the cooling region has a central area of Sichuan Province and its surroundings, and the province as the cooling center has had its air temperature gradually decreased since 1940s. Li et al. (1995) have further studied the cooling in Sichuan Province and indicated the gradual

decrease of global radiation and visibility there. A possible cause has been proposed that an increase of atmospheric aerosols may lead to cooling in Sichuan. The same conclusion has been drawn in studies on climate change of Guizhou Province. Referring to the results measured by China Acid Rain Network, we have found that both Sichuan and Guizhou are the maximal frequency center in occurrence of China acid rain, and are also the minimal pH center of acid rain. Therefore it may result from sulfate aerosols. Tang (1996) and Wang (1996) have made the further studies on climate change in China based on the data of air temperature and precipitation from 400 odd stations throughout China in 1951 — 1990, which were processed under the program of climate-tackling during the eighth five-year period, and the similar conclusions are drawn.

On the other hand, Chen et al. (1994) proposed that all areas in China except for the lower and middle reaches of the Changjiang River and parts of the Huaihe River Basin, have had their precipitation decreased since 1950s, and the decrease in temperature difference between sea and land may result in the decrease of precipitation. In order to further study the climate change in China and its regularities, the laws in variation of other meteorological elements besides air temperature and precipitation should also be investigated. Through studies of the laws in climate change of these meteorological elements, we may obtain more indicative of climate change in China. This is the purpose of the paper. The meteorological elements under investigation include air temperature and precipitation, maximum and minimum mean air temperatures, relative humidity and cloud cover, sunshine duration and scalar wind speed, snow-covered area and depth, and air pressure and soil temperatures at 8 layers from 0 m down to 3. 2 m. Moreover, air temperature in China has increased obviously since 1990s. Therefore the data on air temperature and precipitation are supplemented to 1995 so as to study the variation during 1951 — 1995. This paper is the first part of the work, and emphasis is put on air temperature, precipitation, relative humidity and sunshine duration. The possible mechanism on climate change in China and studies on other meteorological elements will be presented in the second part of the work.

II. DATA AND METHODS OF STUDY

Data from 400 odd stations are used in our study. In order to overcome the inhomogeneity in data distribution in the previous study, i. e. there are denser stations in east part of China and sparser stations in west, we add data in stations west of 105°E as much as possible and properly decrease data from stations in east part. As a result, the number of stations west of 105°E has accounted for 2/5 of the total number of stations under our study.

The time period of data sequence used is from 1951 to 1995 for air temperature and precipitation and from 1961 to 1995 for other meteorological elements. Soil temperature takes measurements at 8 layers from 0 cm (surface) down to 5 cm, 10 cm, 20 cm, 40 cm, 80 cm, 1. 6 m and 3. 2 m. Annual and seasonal mean curves are statistically needed for the whole country and 8 regions. The mean curves throughout China are made as follows: (1) Anomalies from meteorological mean in 1961 — 1990 are taken for meteorological elements at each station. (2) Mean anomalies are calculated for stations in 5° × 5°

(long. /lat.) grid mesh in China. (3) The nationwide means are calculated by multiplying area-weighted coefficient. Meanwhile, the linear tendency distribution and the correlation distribution are also calculated for meteorological element throughout China. The linear tendency coefficients are gained by the least square method. The 8 regions in mainland China are (1) Northeast China (NE), including Heilongjiang, Jilin and Liaoning Provinces and northeastern Inner Mongolia; (2) North China (N); (3) East China (E), including Jiangsu, Jiangxi, Zhejiang, Anhui and Fujian Provinces; (4) Southwest China (SW), including Sichuan and Guizhou Provinces; (5) South China (S), including Guangdong and Hainan Provinces and Guangxi Region; (6) Qinghai-Xizang-Yunnan region (QZY), including Qinghai and Yunnan Provinces and Xizang Region; (7) Northwest China (NW), including Xinjiang and Ningxia Regions and Gansu and Shaanxi Provinces; and (8) Central-South China (C), including Henan, Hunan and Hubei Provinces. In the calculations of air temperature curves and linear tendency, the data from 27 capitals (except Lhasa) of provinces or regions, as well as Beijing and Tianjin have been removed because of the influence due to urban heat island.

III. CLIMATE CHANGE IN AIR TEMPERATURE

Figure 1 gives annual and seasonal mean air temperature anomalies in China in 1952—1995, and the anomalies are taken from the departures in relation to 30-year (1961—1990) means. In the figure, solid lines delineate yearly (or seasonal) air temperature anomaly curves, and dotted lines depict the curves by means of 5-year moving averages. From the annual mean in Fig. 1a it can be seen that, air temperature has its lowest value in 1957, which has been the deepest valley since decreasing from the warming peak in 1940s. Subsequently, the air temperature curve has 5 fluctuations, with peaks at 1961, 1973, 1982, 1990 and 1994 and valleys at 1968, 1976, 1984 and 1992. However, for the 3 fluctuations before 1985, their anomalies at peaks are parallel, i. e. their variations between fluctuations are small. From 1985 on, air temperature abruptly has increased greatly, reaching a high positive anomaly in 1994, which is comparable to the value in 1990 and has been the highest anomaly since 1952.

It is found that the difference in annual mean air temperature from 1957 to 1994 can reach 1. 7°C, but that between the first 5 years in 1950s and the first 5 years in 1990s is only 0. 3°C . According to Chen et al. (1995), the peak air temperature in the 1940s in areas east of 100°E is about 0. 4°C higher than that in the first 5 years of 1950s. If this conclusion is spread to the whole country, it is assumed that the air temperature in the first 5 years of 1990s may not exceed that in 1940s. Concerning seasonal variations, the winter air temperature anomaly has the largest amplitude of fluctuation, autumn and summer are next, and spring has the smallest amplitude. So far as warming after the mid-term of 1980s is concerned, winter and autumn warmings have made the most contributions. Figure 2 shows annual air temperature anomalies for 8 regions. It can be seen that warming in Northeast China (NE) and North China (N) is the clearest, especially in N region (Fig. 2b). In NE region, the warming before 1985 is moderate, but has been obvious since 1985 (Fig. 2a). There exists weak warming in Qinghai-Xizang-Yunnan (QXY) region (Fig. 2f). Warming in East China (E), South China (S) and

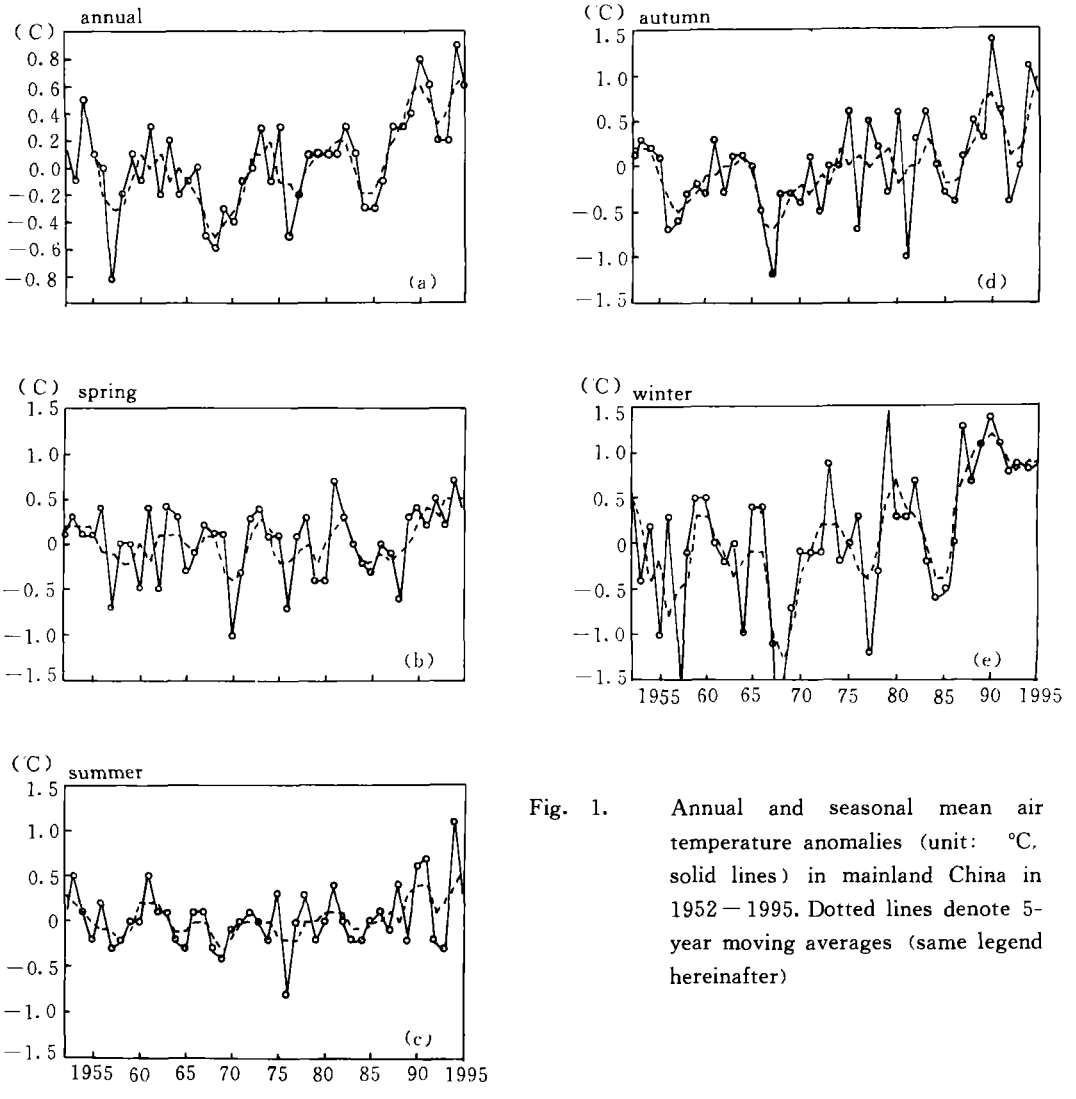

Fig. 1. Annual and seasonal mean air temperature anomalies (unit: °C, solid lines) in mainland China in 1952 — 1995. Dotted lines denote 5-year moving averages (same legend hereinafter)

Central-South China (C) has not been clear since 1952 (Figs. 2c, 2e, 2h), in particular, weak cooling occurs in C region. Obvious cooling appears in Southwest China (SW) (Fig. 2d). Air temperature in SW region reaches the highest in 1940s, and abruptly decreases in 1950s, afterwards gradually cools. Northwest China (NW) has its lowest air temperature in 1960s, then it has a weak warming (Fig. 2g). Therefore, China's warming is mainly in NE and N regions. As opposed to warming, there exists cooling in China, with a center in SW region extending to C region. In order to analyze the variation trend of air temperature in various regions of China, the linear trend distribution of air temperature is shown in Fig. 3. It can be seen from Fig. 3 that, cooling occurs in Sichuan, Guizhou, northern Yunnan, Zhejiang, Fujian, southern Shaanxi and western Henan, as well as western Xizang, some parts of Xinjiang, and western Shanxi. In a word, extensive areas

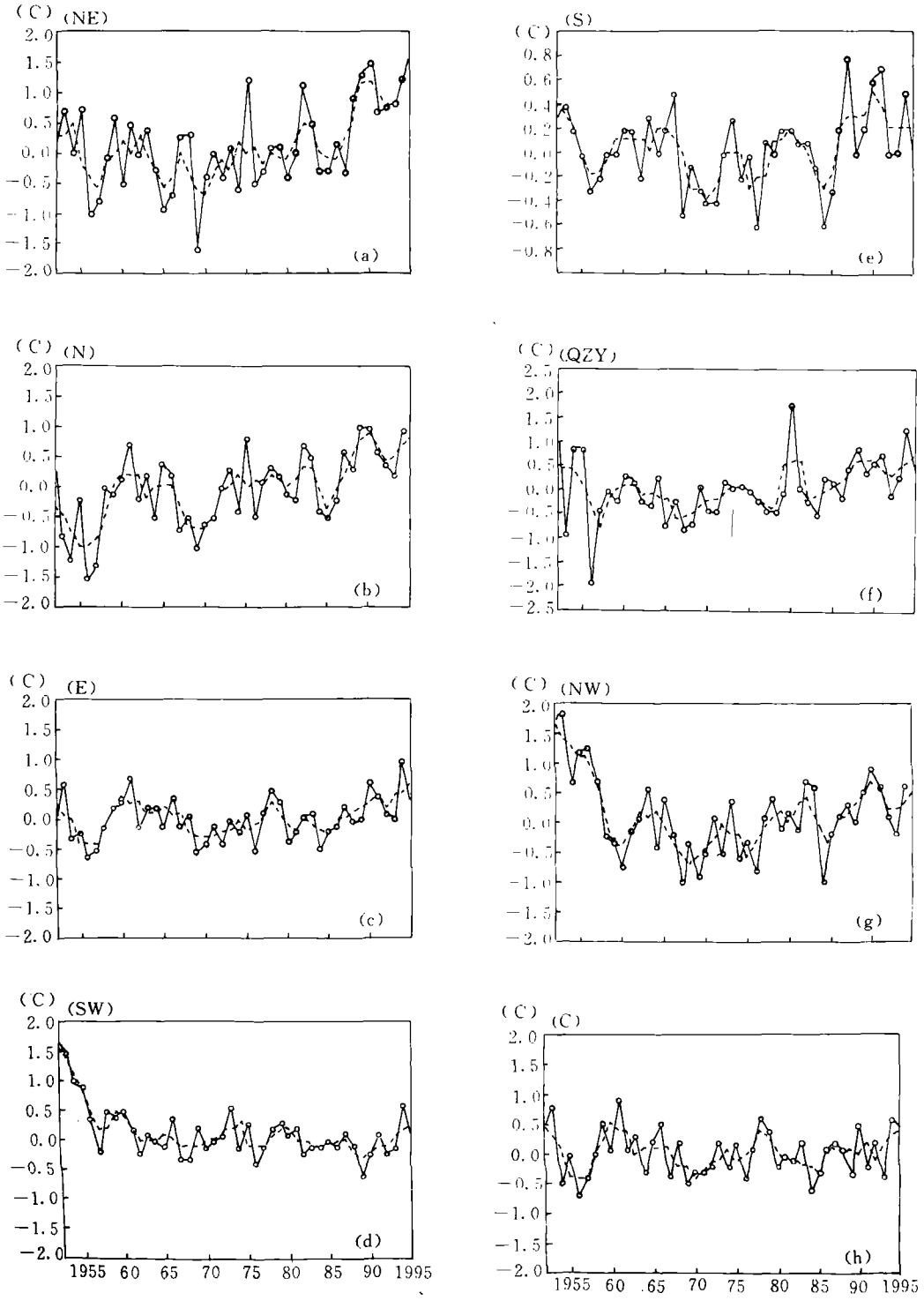

Fig. 2. Annual mean air temperature anomalies (unit: °C, solid lines) in various regions of mainland China in 1952—1995.

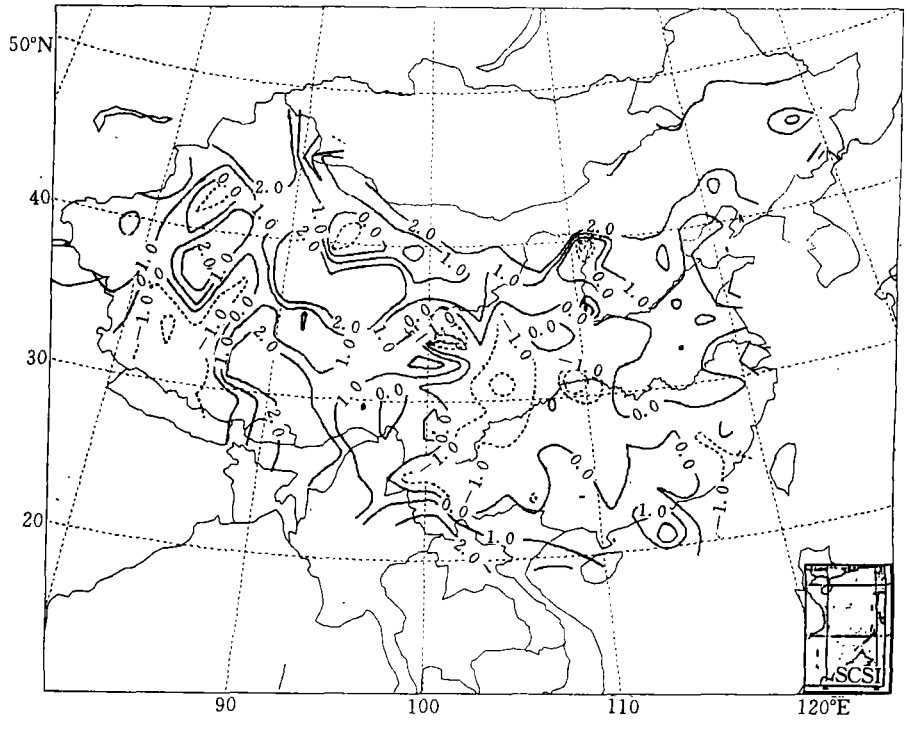

Fig. 3. Linear trend of annual mean air temperature anomalies in mainland China in 1951 — 1990 (unit: 0.01°C a^{-1}, warming positive, cooling negative).

in 35—23°N and east of 100°E are all cooling areas, centered in Sichuan, leading to 0.8°C decrease in 40 years. On the other hand, we can see that, warming areas are placed in areas north of 35°N. The further north the area is, the stronger the warming is. It can be 0.02°C a^{-1} in northern Xinjiang, and 0.03°C a^{-1} in northern Heilongjiang, i.e., a warming of 0.8 —1.2°C in 40 years.

Chen et al. (1991; 1994) analyzed air temperature difference between 1980s and 1950s and annual air temperature anomalies of 1980s in relation to the annual mean of 1961—1990, and also found that a cooling area is located south of 35°N and east of 100°E, which was proved by another our analysis of 1991 — 1995 air temperature anomalies (figure omitted), but the cooling area shrinks, restricted to the area of Sichuan, Guizhou and middle reaches of the Changjiang River.

IV. REGULARITIES OF CLIMATE CHANGE IN PRECIPITATION

Similar to the above air temperature analysis, we have also drawn the annual and seasonal precipitation anomaly curves in mainland China in 1951—1995 (Fig. 4), annual precipitation anomaly curves in 8 regions of China (Fig. 5), and linear trend distribution of annual precipitation anomalies (Fig. 6). From Fig. 4a we can see that, during the period of 1951—1995, the annual precipitation has its peak value occurring in the first 5 years of 1950s, then followed by many fluctuations with a small decrease tendency. In comparison with annual precipitation in 1950s, it is decreased by about 20 mm, and mainly occurred in

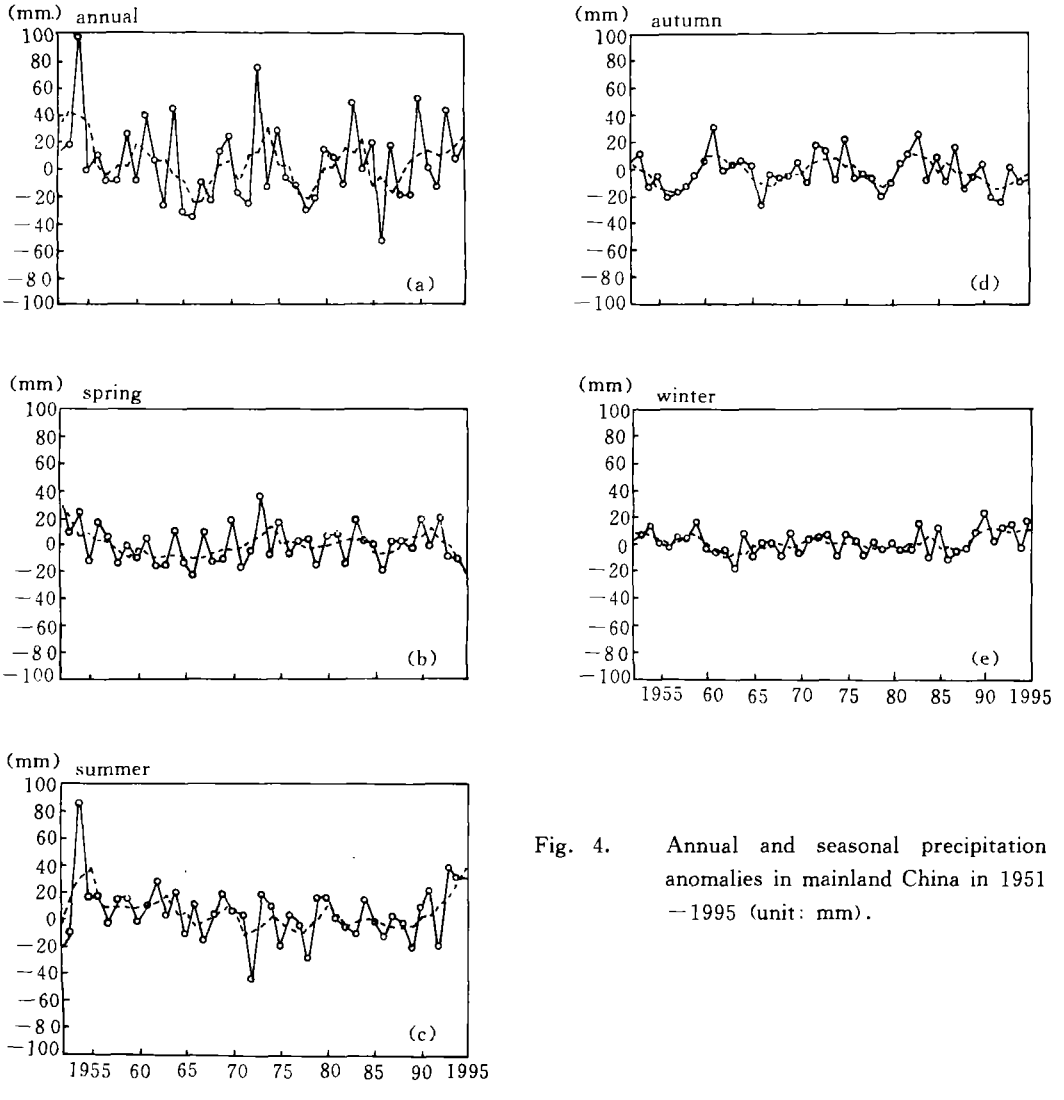

Fig. 4. Annual and seasonal precipitation anomalies in mainland China in 1951—1995 (unit: mm).

1950s—1960s. The decrease of annual precipitation is not clear after 1960s. As a whole, years 1954, 1973, 1983 and 1990 are wet (high flow year), and years 1966, 1972 and 1986 are dry (low flow year). Quasi-periodic oscillations of 2, 11 and 4 years can be found evidently from Fig. 4a. As to seasonal precipitation, spring and summer precipitations decrease very obviously year by year (Figs. 4b and 4c), and autumn and winter precipitations vary stably (Figs. 4d and 4e). The summer precipitation has had an increasing tendency since 1990, but its precipitation amount does not exceed that in the first half of 1950s.

Among the 8 regions of mainland China, N region is the most obvious area in annual precipitation decrease (Fig. 5b). Its annual precipitation has decreased since 1950. The precipitation amount in 1950s is 80 mm higher than that in the first 5 years of 1990s. Annual precipitation decrease also occurs in NE, E and QZY regions (Figs. 5a, 5c and

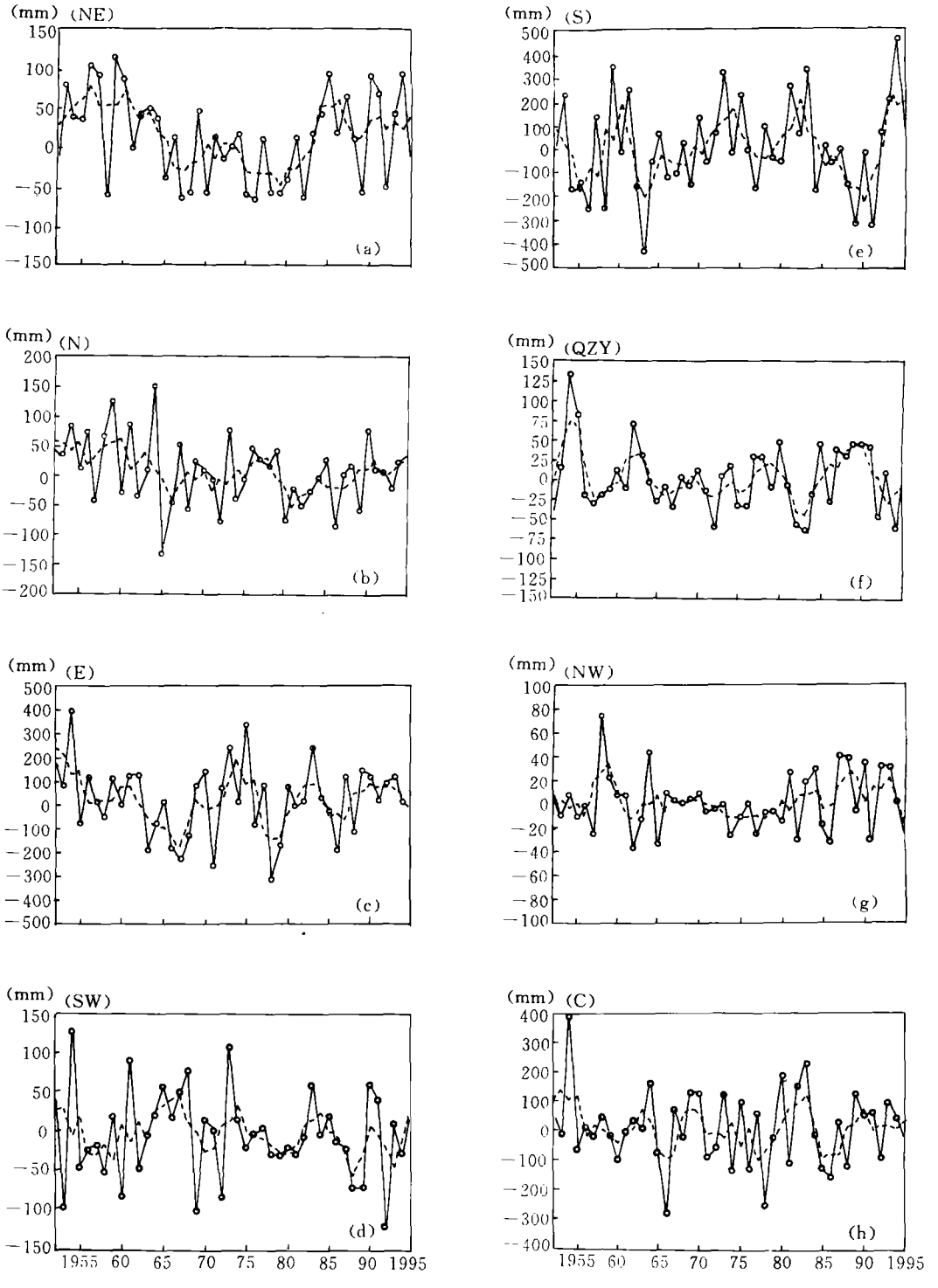

Fig. 5. Annual prècipitation anomalies in various regions of mainland China in 1951 — 1995 (unit: mm).

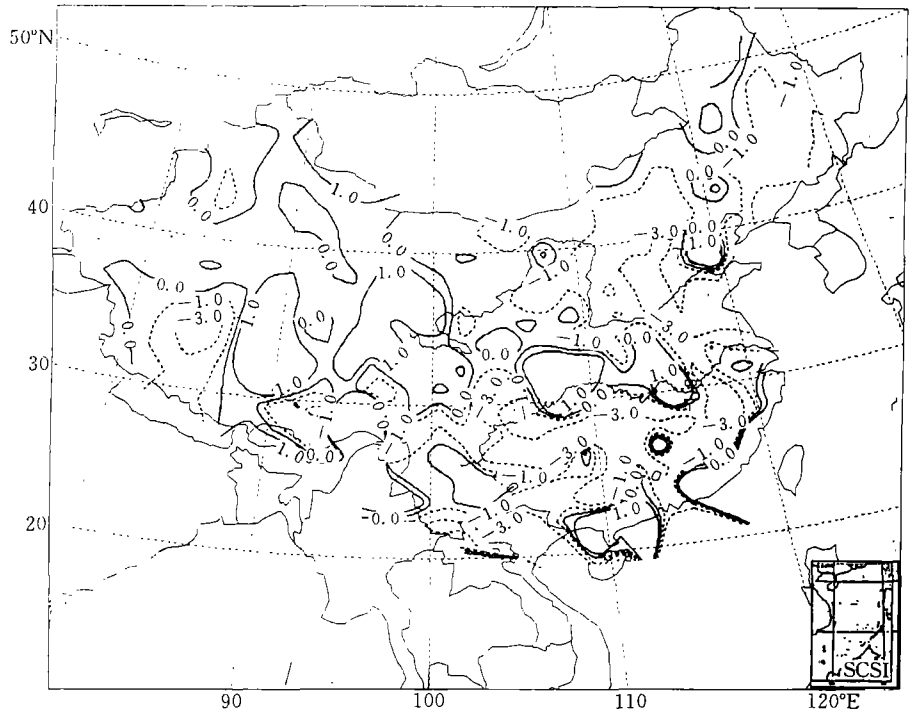

Fig. 6. Linear trend of annual precipitation anomalies in mainland China in 1951 — 1990 (unit: mm a^{-1}).

5f), but NE region has obviously increased its precipitation since 1985. S and NW regions have also increased precipitation (Figs. 5e and 5g), and other regions remain rather stable precipitation (Figs. 5d and 5h).

From Fig. 6 we can see that, the area east of 100°E except northern Northeast China, between Changjiang River and Huaihe River, and western Guangxi, has its precipitation decreased, in which North China ranks first in precipitation decrease, but Changjiang-Huaihe River Basin ranks first in precipitation increase and has suffered from flooding many times since 1980s. On the other hand, the area west of 100°E except western Xizang and Xinjiang, and southeastern Xizang has its precipitation increased. As a whole, the area with precipitation decrease is far larger than that with precipitation increase, and decrease center generally reaches a strength of 3 mm a^{-1}, but increase center only 1 mm a^{-1}. The above values have passed through a significance test of 0.05. In summary, since 1950s mainland China has become drier, but not serious.

V. CLIMATE CHANGE IN MAXIMUM AND MINIMUM AIR TEMPERATURE

From Fig. 7 of annual and seasonal mean maximum air temperature anomalies during periods of 1961 — 1995 we can see that, in relation to annual mean, the maximum air temperature has such a variation that it reaches the highest in the early 1960s, then is followed by decreasing, and turns to increasing after 1984, and in the 1990s it exceeds the level of the first 5 years of 1960s (Fig. 7a); in relation to seasonal mean, spring and

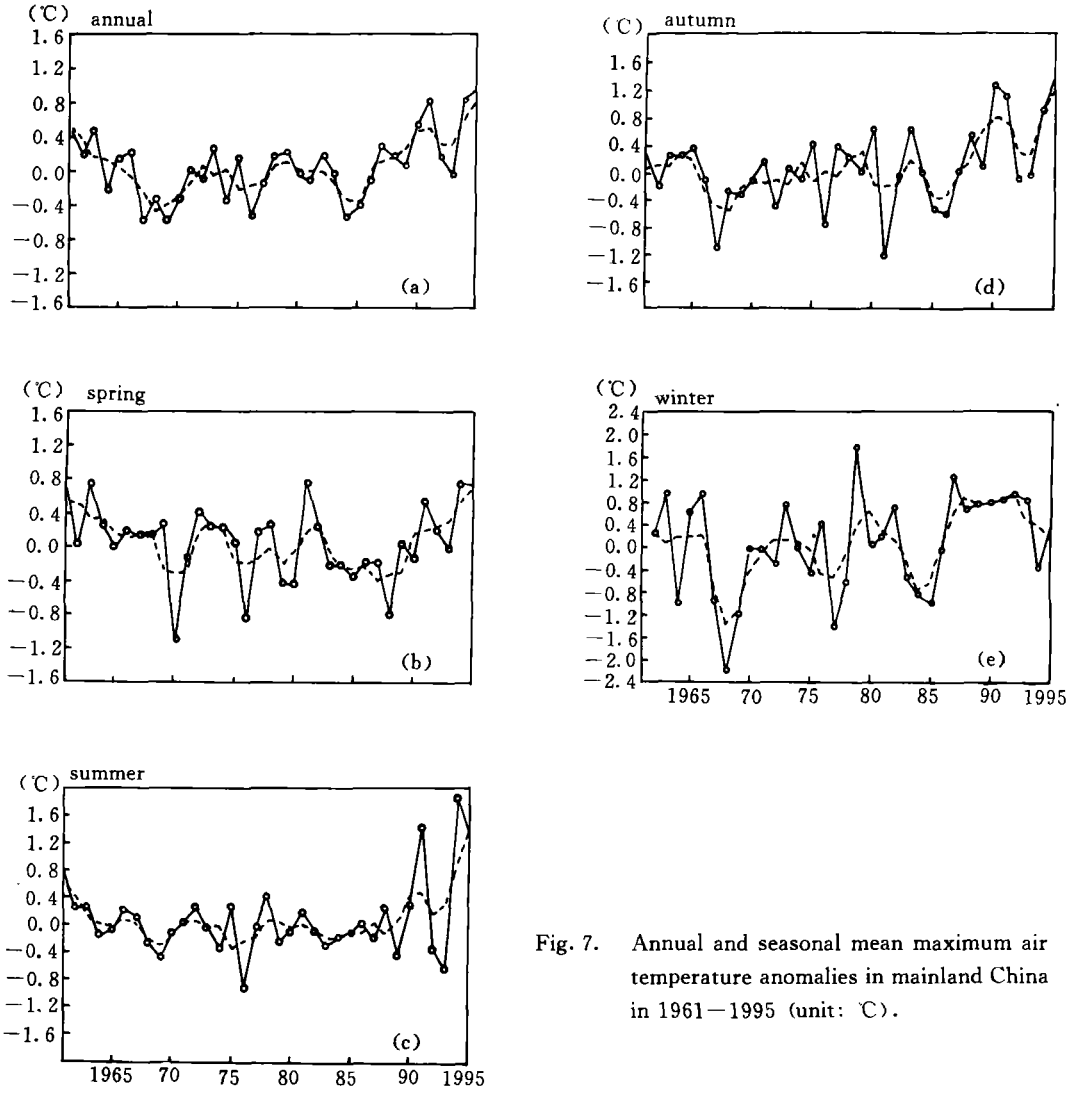

Fig. 7. Annual and seasonal mean maximum air temperature anomalies in mainland China in 1961—1995 (unit: ℃).

summer maximum air temperatures have a consistent variation with annual one, and their increases begin from 1988 and 1989, respectively (Figs. 7b and 7c); on the other hand, winter maximum air temperature varies greatly (Fig. 7e), but autumn one varies slightly before 1986 and afterwards increases obviously (Fig. 7d). As pointed in Section III that, the annual mean air temperature in mainland China has a stable variation before 1985, and after that it increases abruptly and greatly. The seasonal mean maximum air temperatures have all increased since the second 5 years of 1980s, especially for summer and autumn seasons. Therefore, warming in the whole country after 1985 is not mainly attributed to winter warming. Conversely, summer warming makes a considerable contribution.

From Fig. 8 of annual and seasonal mean minimum air temperature anomalies during periods of 1961—1995 we can see that, in relation to annual mean, the minimum air temperature has obviously increased in recent 30 years, especially after 1985 (Fig. 8a); in relation to seasonal mean, they all turn to warming (Figs. 8b—8e). Therefore, we can say

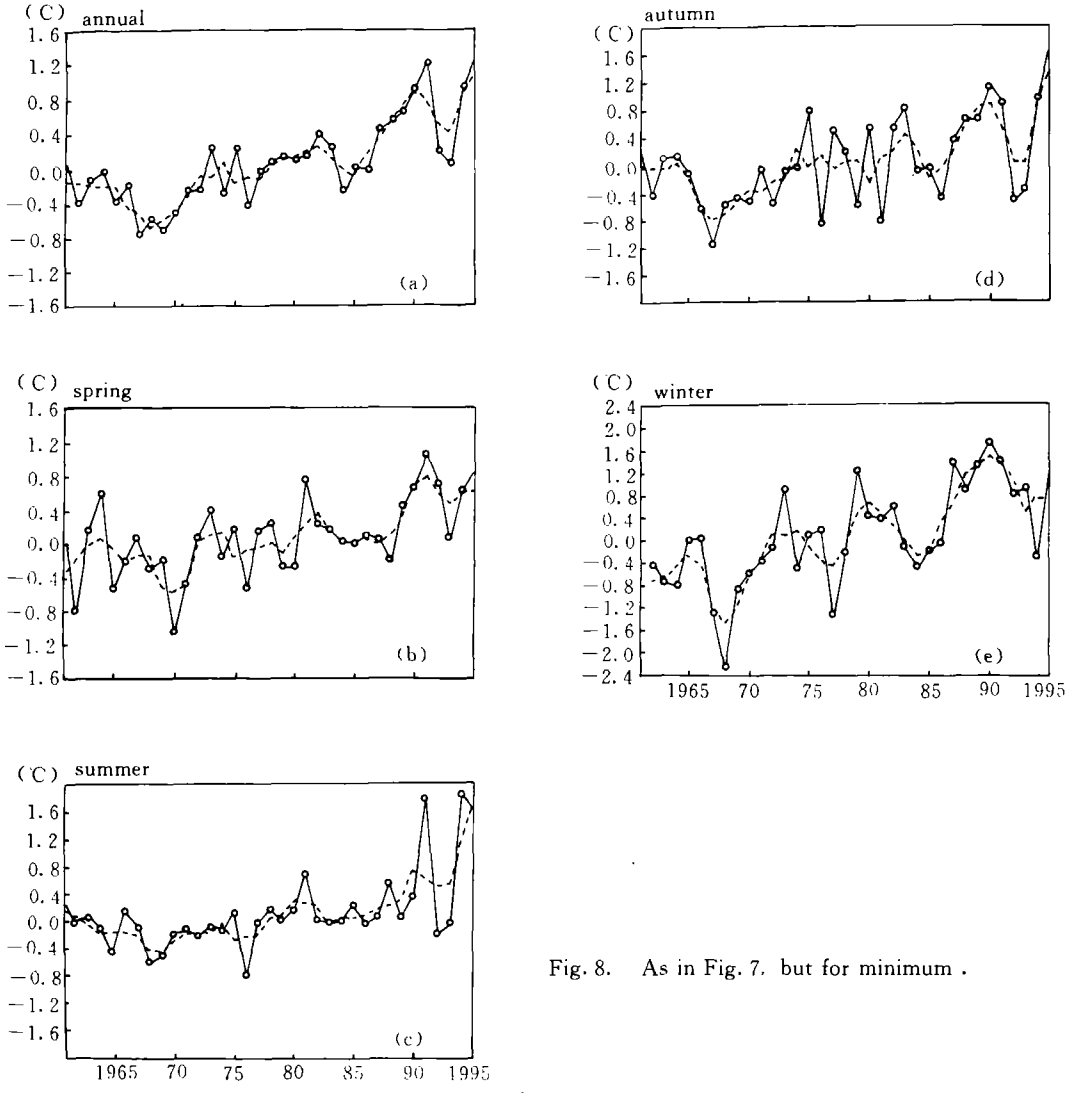

Fig. 8. As in Fig. 7, but for minimum.

that climate in China before 1985 is characterized by a slight cooling of daytime air temperature and a warming of nighttime air temperature, but the latter larger than the former. This is in agreement with the global change of air temperature, i.e. the maximum air temperature has slight variation but the minimum one warms evidently. However, both maximum and minimum air temperatures have warmed since 1985, i.e. warming in China after 1985 is not wholly attributed to warming of minimum air temperature.

Figures 9 and 10 delineate linear trends of annual mean maximum and minimum air temperature anomalies in 1961—1990, respectively. It is seen from Fig. 9 that, warming area is located in the area east of 105°E and north of 36°N, and cooling area is located south of 36°N. They agree nearly with areas of warming and cooling of annual mean air temperature. However, in area west of 105°E, positive and negative values of linear trend of annual mean maximum air temperature anomalies are distributed irregularly. It is seen from Fig. 10 that, the whole China except western Xizang has almost been warming in the

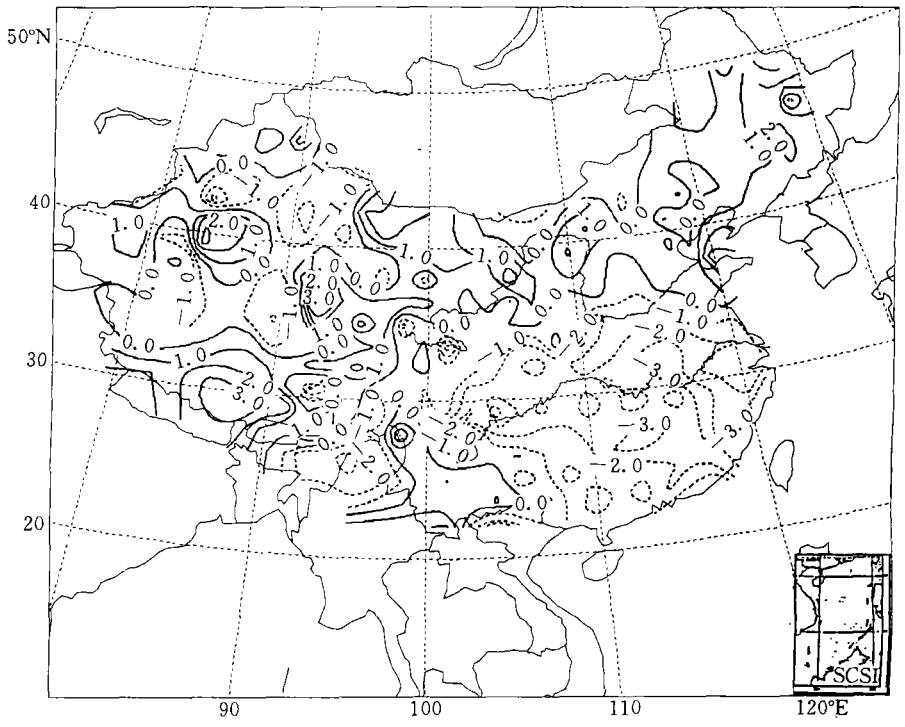

Fig. 9. Linear trend of annual mean maximum air temperature anomalies in mainland China in 1961—1990 (unit: 0.01°C a^{-1}).

linear trend of minimum air temperature, with its warming rate higher than that of maximum air temperature.

In summary, the further north, the more obvious warming. Therefore, it is found from linear trends of maximum and minimum air temperature anomalies that, the warming area east of 100°E and north of 35°N has both maximum and minimum air temperatures warmed. But warming in minimum air temperature is more evident, and thus it plays a more important role in warming of air temperature. On the other hand, the cooling area south of 35°N has maximum air temperature cooled but minimum air temperature warmed, with the absolute value of cooling in maximum air temperature higher than that of warming in minimum one. Thus the cooling in maximum air temperature plays an important role in cooling of air temperature. The above mechanism is suitable for Xinjiang cooling area, but not for cooling area of western Qinghai-Xizang Plateau, because of both cooling in maximum and minimum air temperatures there, especially cooling in minimum one.

VI. REGULARITIES OF CLIMATE CHANGE IN RELATIVE HUMIDITY

From Fig. 11 of annual and seasonal mean relative humidity anomalies in 1961—1995 we can see that, the annual mean seems to be stable before 1985, within an amplitude of 10% (Fig. 11a). However, it increases after 1986, with an increment of 2%—3% anomalies. The clearest increase occurs in winter season (Fig. 11e), and next in summer

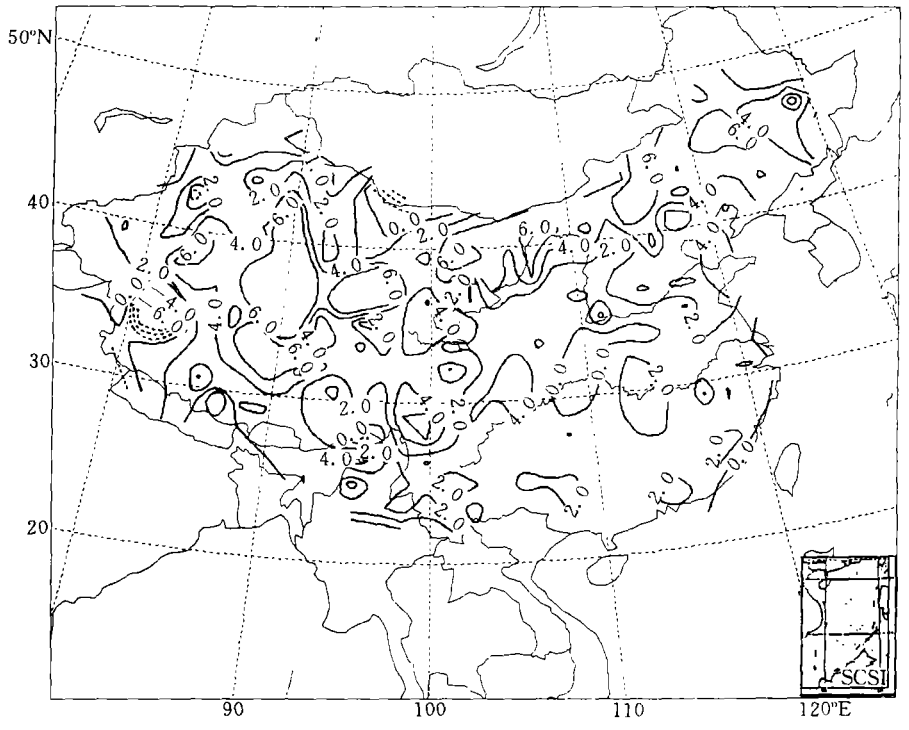

Fig. 10. As in Fig. 9. but for minimum.

(Fig. 11c). In reference to precipitation anomalies (Fig. 4), the winter precipitation (Fig. 4e) is not found to increase obviously. From the linear trend of annual mean relative humidity anomalies (figure omitted) we can see that, there is an increase belt of relative humidity between Changjiang River and Huaihe River, and decrease areas are located in Northeast China, North China, lower and middle reaches of the Changjiang River, and areas south of upper reaches of the Changjiang River. These areas of increase or decrease are in agreement with those of precipitation. They have central values of 0.1% a^{-1} for either decrease or increase areas, accounting for a variation of 3% in 30-year relative humidity anomalies. It is also seen that, northern Xinjiang and western Xizang are increase area with a center of 0.15% a^{-1} or more, amounting to an increase of 4.5% in 30-year relative humidity anomalies. In addition, southern Xinjiang desert and mid-west part of the Qinghai-Xizang Plateau are in decrease area. In a word, climate change is not obvious in representation of relative humidity.

VII. CLIMATE CHANGE IN SUNSHINE DURATION

From Fig. 12 of annual and seasonal mean sunshine duration anomalies in 1961—1995 we can see that, the year 1965 has the largest sunshine duration in the last 35 years, and subsequently always decreases until 1990s (Fig. 12a). From the second 5 years of 1960s to the first 5 years of 1990s, its anomalies decrease approximately linearly from +60 h a^{-1} to −90 h a^{-1}, amounting to 150 h in 30 years, on an average decrease of 5 h a^{-1}. We also can see that, the most decreasing season is winter (Fig. 12e), and next is summer

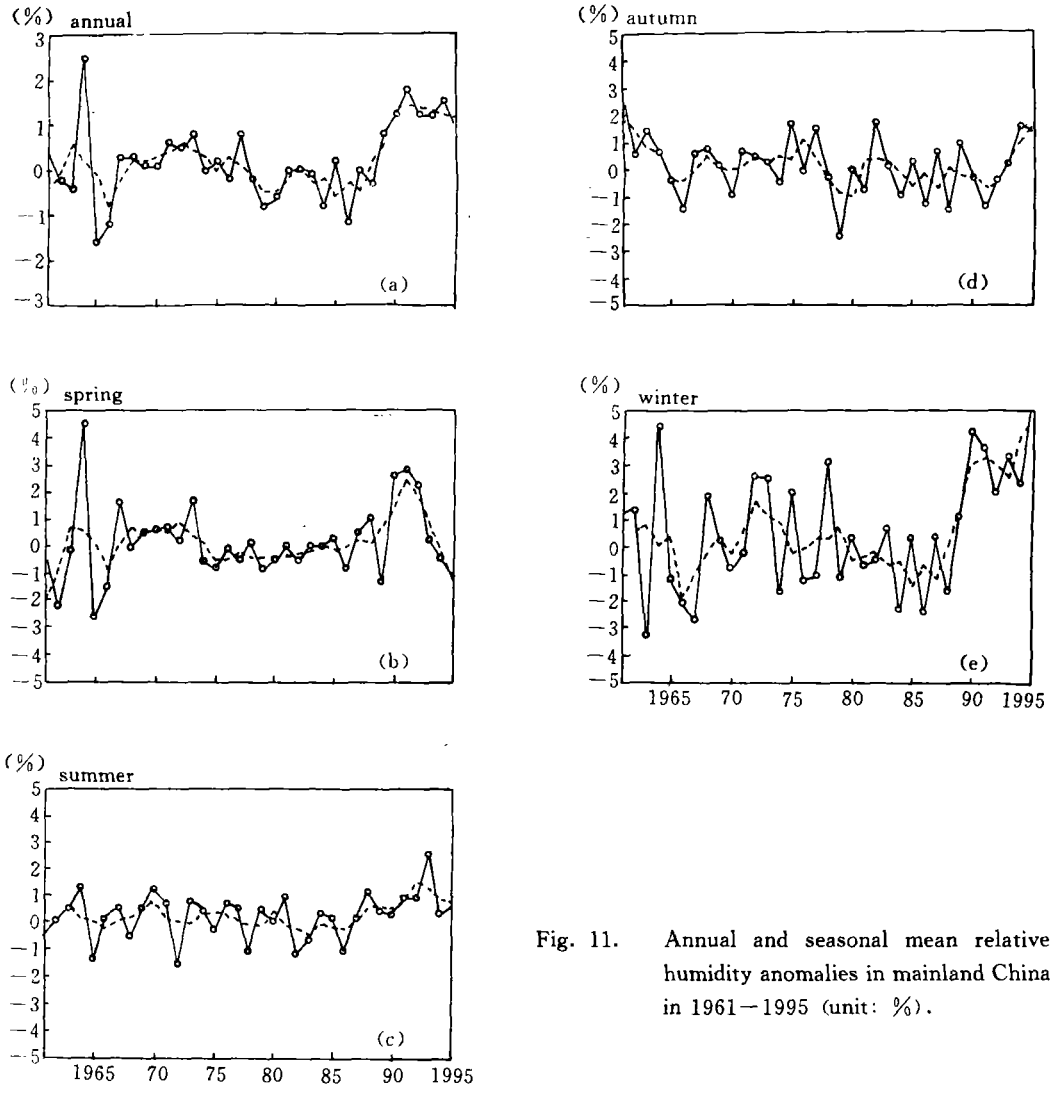

Fig. 11. Annual and seasonal mean relative humidity anomalies in mainland China in 1961—1995 (unit: %).

(Fig. 12c). Figure 13 depicts the linear trend of annual mean sunshine duration. It is seen from the figure that the area north of 35°N is mainly the area of increase, and south of 35°N is that of decrease. In comparison with the linear trends of air temperature (Fig. 3), maximum and minimum air temperatures (Figs. 9 and 10), it can be found that the warming areas correspond to the increasing sunshine duration areas, and the cooling areas south of 35°N correspond to the decreasing ones, and that the decreasing sunshine duration areas agree with the decreasing areas of maximum air temperature, indicating that an area has decreasing sunshine duration and maximum air temperature, thus decreasing air temperature.

VIII. CONCLUSIONS

As the first part of the work, this paper describes the climate change in air temperature and precipitation in China in recent 45 years, and the climate change in

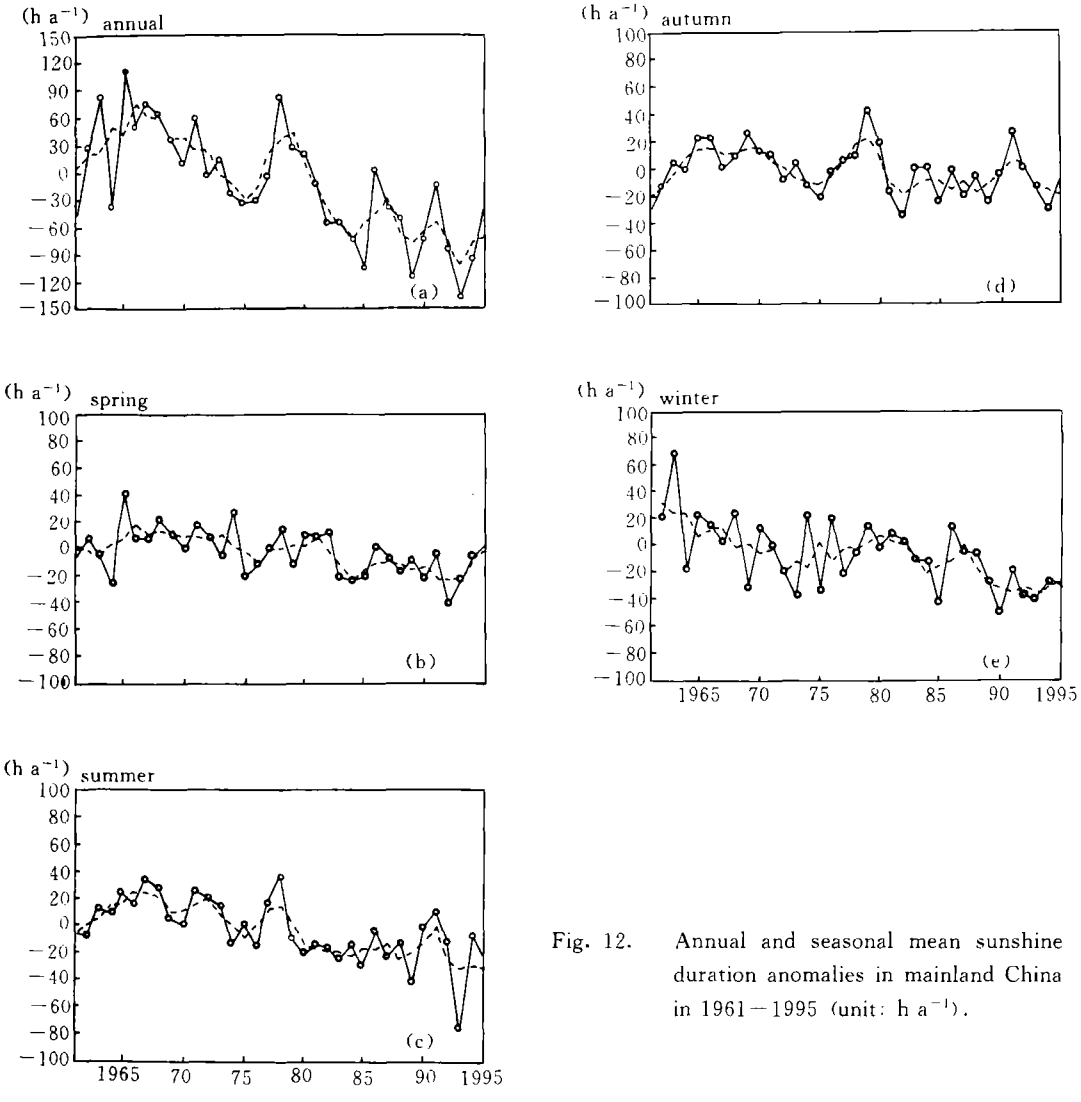

Fig. 12. Annual and seasonal mean sunshine duration anomalies in mainland China in 1961—1995 (unit: h a^{-1}).

maximum and minimum air temperatures as well as in relative humidity and sunshine duration. On basis of the above analyses the following facts in climate change can be concluded.

(1) Air temperature in China has reached the first warming period of the century in the 1940s (Zhang et al. 1982; Chen et al. 1994), then abruptly decreased in the 1950s, and is subsequently followed by oscillating variations. Since late 1980s, it has greatly increased again, and reached the second warming period of this century in the first 5 years of 1990s. Annual mean air temperature in mainland China has been increased by 0.3°C from the first 5 years of 1950s to those of 1990s. It is estimated from the above facts that, air temperature in the first 5 years of 1990s has not reached, or just has approached to that of the 1940s. Moreover, the climate change in air temperature is very complicated in various regions, with warming and cooling areas simultaneously distributed.

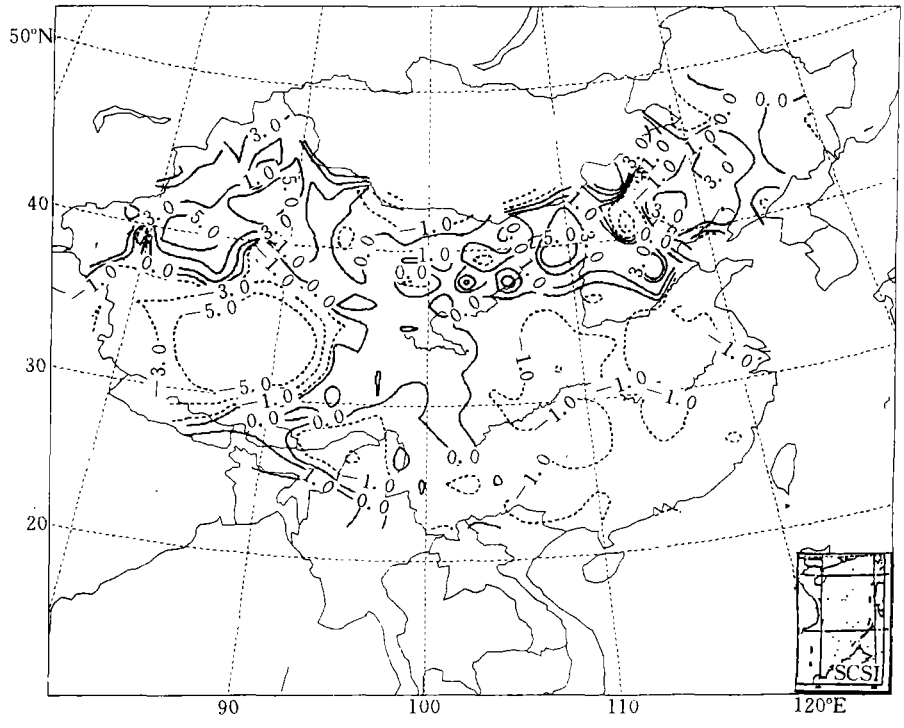

Fig. 13. Linear trend of annual mean sunshine duration in mainland China in 1961 — 1990 (unit: 10 h a^{-1}).

(2) Warming of modern air temperature in China mainly occurs in areas north of 35°N, with the highest warming in Xinjiang and northern Heilongjiang. On the contrary, there exists an extensive cooling area from 35°N southward to 23°N and east of 100°E, with cooling centers mainly located in Sichuan, Guizhou and southern Shaanxi. The cooling area can extend to the coastal areas of East China from Jiangsu to Fujian. The warming area is mainly characterized by increases of minimum air temperature and sunshine duration. Different from other regions, warming in China is not mainly due to the warming in winter. Furthermore, warming in summer cannot be ignored, and in some areas it may exceed the warming in winter. The main characteristics of the cooling area are shown in decreases of maximum air temperature and sunshine duration. Therefore, the cooling area is attributed to the decrease of daytime sunshine duration, thus the decrease of daytime maximum air temperature. Causes for this phenomenon need to be studied further. Li et al. (1995) have pointed out that cooling in Sichuan may be due to the increase of sulfate aerosols caused by air pollutions there. This possibility may be true, and will be studied in the second part of the work.

(3) Annual precipitation in China in recent 45 years has decreased slightly, with major decreasing area located in North China and south of the Changjiang River. Conversely, precipitation in Changjiang-Huaihe River Basin is increased, mainly in the 1980s up to 1995. This increase is in agreement with the summer — autumn flooding occurring frequently there in the 1980s up to 1995.

REFERENCES

Chen Longxun et al. (1991). Preliminary analysis of climatic change during the last 39 years in China. *Quart. J. of App. Meteor.*, **2**: 164—173 (in Chinese).

Chen Longxun et al. (1992). The Characteristics of interannual variations of the East Asian Monsoon. *J. Met. Soc. Japan*. **70**: 397—421.

Chen Longxun et al. (1994). Climate change in China during the past 70 years and its relationship to the monsoon variations. *Climate Biosphere Interaction: Biogenic Emissions and Environmental Effects of Climate Change*. Edited by Richard G. Zepp. John Wiley and Sons. Inc. pp. 31—49.

Chen Longxun et al. (1995). Preliminary Analysis of Historical Temperature and Precipitation Baseline for China 1—43. Submitted to U. S. Country Studies Management Team and Department of Science and Technology for Social Development. The State Science and Technology Commission of China.

Li Xiaowen et al. (1995). The cooling of Sichuan Province in recent 40 years and its probable mechanisms. *Acta Meteor. Sinica*. **9**: 57—68.

Lin Xuechun et al. (1990). Climatic trend in China in recent 40 years. *Meteor. Monthly*. **10**: 16—21 (in Chinese).

Tang Guoli (1996). Analysis of trend variations in standard series of air temperature in China. in *Collected Papers of Climate Change and Its Numerical Simulation*. Vol. 1. China Meteor. Press. Beijing. pp. 196—199 (in Chinese).

Tu Qipu (1984). Tendency and period of air temperature variations in China in last hundred years. *J. Nanjing Ins. Meteor.*, **2**: 151—161 (in Chinese).

Wang Bomin (1996). Analysis of trend variations in standard series of precipitation in China. in *Collected Papers of Climate Change and Its Numerical Simulation*. Vol. 1. China Meteor. Press. Beijing. pp. 200—206 (in Chinese).

Zhang Xiangong et al. (1982). Some characteristics of air temperature variations in China in this century. *Acta Meteor. Sinica*. **40**: 198—208 (in Chinese).

Zhao Hanguang et al. (1989). Temporal and spatial variation in abnormal winter warming in China and analysis of its circulation characteristics. *Meteor. Monthly*. **5**: 16—20 (in Chinese).