An Aridity Trend in China and Its Abrupt Feature in Association with the Global Warming

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ABSTRACT

A distinct aridity trend in China in last 100 years is presented by applying a linear fitting to both the climate records and the hydrological records, which is supported by evidence of environmental changes and seems to be associated with a global warming trend during this period.

The Mann Kendall Rank statistic test reveals a very interesting feature that the climate of China entered into a dry regime abruptly in about 1920's, which synchronized with the rapid warming of the global temperature at almost the same time.

According to an analysis of the meridional profile of observed global zonal mean precipitation anomalies during the peak period of global warming (1930–1940), the drought occurred in whole middle latitude zone (25°N–55°N) of the Northern Hemisphere, where the most part of China is located in. Although this pattern is in good agreement with the latitude distribution of the difference of zonal mean rates of precipitation between $4 \times CO_2$ and $1 \times CO_2$ simulated by climate model (Manabe and Wetherald, 1983), more studies are required to understand the linkage between the aridity trend in China and the greenhouse effect.

The EOF analysis of the Northern Hemisphere sea level pressure for the season of June to August shows an abrupt change of the time coefficient of its first eigenvector from positive to negative in mid-1920's, indicating an enhancement of the subtropical high over Southeast Asia and the western Pacific after that time. This is an atmospheric circulation pattern that is favorable to the development of dry climate in China.

I. INTRODUCTION

The drought problem, which has profound effects on the water resources on a global scale, is now becoming a serious environmental issue. A great number of researches have addressed the drought and aridity trend problem in different regions all over the world from meteorological point of view (e.g. Wilhite and Easterling, 1987; Karl and Knight, 1985; Palmer and Denny, 1971; Namias, 1966; Coughlan et al., 1976 and Wigley and Atkinson, 1977). The persistent drought in the African Sahel region since late 60's has long been one research focus in this area (e.g. Charney, 1975; Parker et al., 1986; Lamb, 1983; Nicholson, 1985). The drought in United States in 1988 has been also extensively reported and attempts have been made to understand the causes of drought (e.g. Karl and Young, 1987; Palmer and Brankovic, 1989; Trenberth et al., 1988; Namias, 1989).

This paper aims to present the evidence of a distinct aridity trend in China in last 100 years, to examine the abrupt features of its evolution, and to discuss the possible association with global warming. Section II applies a linear fitting to the climatological records and the hydrological records to examine the aridity trend of China and then the Section III provides the evidence of environmental changes to support the aridity trend. Section IV is the detection of abrupt change signal of the aridity index by the Mann Kendall Rank statistic test. Section V has analyzed the synchronous nature of the climate change in China with the changes of global mean temperature. Section VI makes an attempt to understand the possible linkage of aridity trend in China with the greenhouse effect by looking at the global precipitation pattern observed during the peak period of warming (1930–1940) and that from the global climate model simulation. Section VII has analyzed the regional circulation pattern related to arid climate of China. The conclusions and discussion are included in the last section.

II. THE ARIDITY TREND IN CLIMATIC AND HYDROLOGICAL RECORDS

In detecting the trend, a linear fitting is applied to the drought and flood indices of China, summer monsoon rainfall, length of plum rains period (Meiyu) and the discharge of the Yangtze River since 1887.

Here the drought and flood indices are defined by

$$I_d = n_{4+5} / N,$$
$$I_w = n_{1+2} / N,$$

where N is the total number of stations (100); n_{4+5} is the number of stations with precipitation grades of 4 and 5; n_{1+2} is the number of stations with precipitation grades of 1 and 2. The amount of precipitation is classified into five grades based on the following criteria,

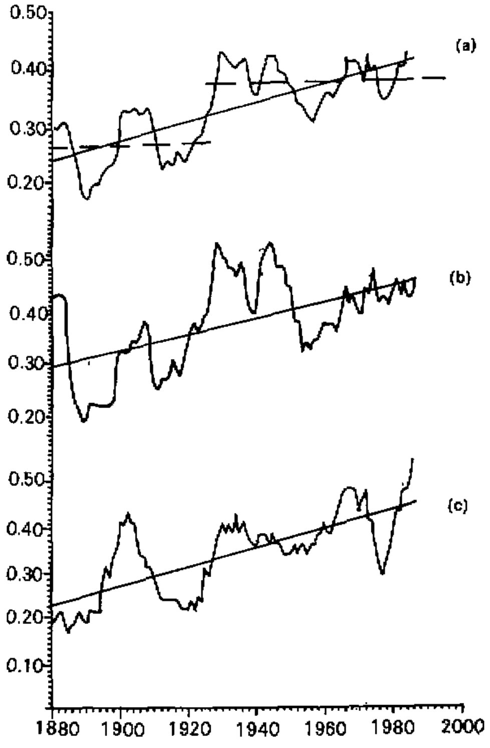

Fig.1. 10-year running means of drought indices and their linear fittings: (a) to (c) drought indices of China, northern China and southern China respectively.

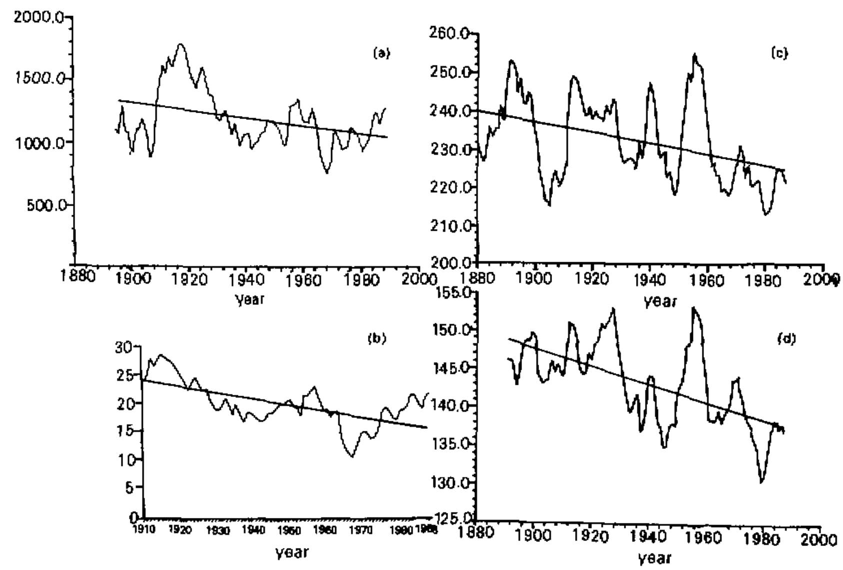

Fig.2. 10-year running means of summer monsoon rainfall (a) number of days of plum rains period (b) river discharge of the Yangtze River at the Wuhan station (middle-reaches) (c) and Yichang station (upper-reaches) (d) and their linear fittings.

grade 5: $\Delta R / R < -50\%$
grade 4: $-50\% < \Delta R / R < -25\%$
grade 3: $-25\% < \Delta R / R < +25\%$
grade 2: $+25\% < \Delta R / R < +50\%$
grade 1: $+50\% < \Delta R / R$

where $\Delta R / R$ is percentage of the precipitation departures in the rainy season (May to September).

The drought and flood indices of China. is calculated by using 100 stations data, but there are no stations to the west of 100°E, because no long-term records are available in that region. In calculating the indices, some proxy data are also included in classification of precipitation for the stations which have no instrumentation records during the early period. These data are taken from the Appendix of Atlas of Drought and Flood Distribution of China (1470–1979) (State Meteorological Administration of China, 1980).

Fig.1 presents 10 years running means of drought and flood indices of China, and South China and South China and their linear fittings since 1880. A significant increasing trend is shown in all three drought indices. The drought index for whole China increased from 0.25 to 0.41 in the past 108 years (Fig.1a). The same amplitude of increasing drought index occurred in both North China and South China as divided by the Yangtze River about 30°N (Figs.1b, c). On the other hand, all three wet indices show a decreasing trend, although their slopes are much less than the drought indices. That means a distinct aridity trend appeared in China, not only in North, but also in South in China in the last 100 years.

Superimposed on this long-term trend, there is an oscillation with the period of about 36 years, the so-called "Brucker period" which is supposed to be related to the solar activities. Howeve, it will not be dicussed in this paper.

More evidence of aridity trend in China is presented by Fig.2: the decrease of summer monsoon rainfall in East China from 1350 mm to 1050 mm in 100 years(Fig.2a); the decrease of length of plum rains period, i.e. the number of days of Meiyu season in the lower and middle reaches of the Yangtze River valley decreases from 24 days to 15 days in the period of 1910 to 1988 (Fig.2b). The plum rains or so-called Meiyu appear around the period from June 20 to July 15, when the plum is in its harvest period. During this period, the climate is characterized by high temperature and humidity which is related to the onset of summer monsoon in East China (Tao, 1964).

The hydrological records of the Yangtze River (the largest river in China) also show an aridity trend. The yearly river discharge at Hankou station (middle-reaches) reduced from $240 \times 10^9 m^3$ to $225 \times 10^9 m^3$ since 1880 (Fig.2c) and that of Yichang station (upper reaches) reduced from $149 \times 10^9 m^3$ to $138 \times 10^9 m^3$ since 1890 (Fig.2d). These features are in consistent with those in the climatic records.

III. SOME EVIDENCE OF ARIDITY TREND FROM THE ENVIRONMENTAL CHANGES

Although there is no direct long-term measurement of climatic and hydrological records in western China, a large amount of evidences of environmental change indicate indirectly that the aridity trend appears in that area, too.

(1) Increase of drought occurrence frequency (DOF) from the historical literature.

In the arid region, the DOF was 20% in the period of 1760-1919, but has increased to 42% since 1920. In the semi-arid region, the DOF was 18% in the period of 1650-1859, while it has reached about 37% since 1900 (Fu, 1989).

(2) Reduction of lake level and lake area and even disappearance of some inland lakes.

According to the data from Uygur Autonomous region of Xinjiang, the total lake area of that region has decreased about 4952 km2 from 1950's to 1980's. A typical sample is the disappearance of famous Lop Lake since 1970's, while it was about 3006 km^2 during the 1950's (Li, 1988).

Another example is the Qinghai Lake. It is the largest salt lake and an inland lake in China. Therefore it is very sensitive to the climatic variation. The decreasing trend of lake level started at the beginning of this century. Table 1 lists the lake level and lake area in three representative periods. In this century, it has decreased its water level by 11.18 m and its area by 640 km^2. Since 1956, there is a systematic observation in this lake area. During the period of 1956 to 1986, the lake area decreased at a rate of 11 km^2 per year. The lake level lowered at a rate of 10.8 cm per year (Shi, 1989).

Table 1. Variation of Qinghai Lake in This Century

Year	Lake Level (m)	Lake Area (km^2)
1908	3205	4980
1957	3196	4568
1981	3193	4340

(3) The retreat of mountain glacier

This is an index of both the decreasing of precipitation and the warming of temperature. According to the statistics of glaciers in Northwest China (Table 2), 56% are in retreat, 23%

are in advance and 21% remain not affected significantly. The average speed of retreat glacier is about 10–20 m / year with the maximum of 100 m. (Shi, 1989).

(4) The expansion of desertification land

In past 40 years, the desertification occurred mainly in the semi-arid zone of northwestern part of the country. It is estimated that the desertificated land was expanding at the rate of 1560 km^2 per year (Dong, 1989).

Additional evidence of an aridity trend in China is a decrease in the underground water level, etc. (*Climate, No.5, Blue Book of Science and Technology of China, 1990*).

Although there should be many anthropogenic factors involved in the environmental changes, the decreasing trend of precipitation as shown in last section is still a major factor in the development of aridity trend.

Table 2. Variation of Mountain Glacier over Northwest China since 1950's (Shi, 1989)

Name	Number of Glacier	Variation of Glacier (%)		
		Advance	Retreat	Stable
Altay	416	20	80	0
Tianshan M.	8908	12	67	21
Qilian M.	2895	18	57	25
Kuenren M.	7774	37	21	42
Pamirs	2112	18	64	18
KaraKuenren M.	1848	33	47	20
	mean	23	56	21

IV. *THE ABRUPT FEATURE OF ARIDITY DEVELOPMENT AT ABOUT 1920's*

As shown in Fig.1a, the drought index of China exhibits a significant change around the early 1920's. The mean of dry index increased abruptly from 0.27 to 0.37 at that time.

In order to detect this abrupt change more quantitatively, the Mann Kendall Rank statistic test (Goossens and Berger, 1987) was applied to the time series of drought index. Among the many tests used to detect a climatic change, such as the low pass-filter, Cramer's test, ratio of signal to noise and so on, this Mann Kendall Rank statistic test seems to be the most appropriate one allowing to detect the approximate beginning of an abrupt climatic change.

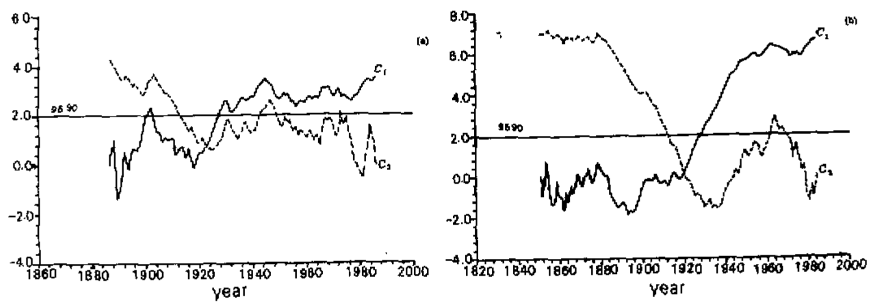

Fig.3. Mann Kendall Rank statistic tests for drought index of China (a) and the Northern Hemisphere air temperature over land (b) (Jones et al., 1986).

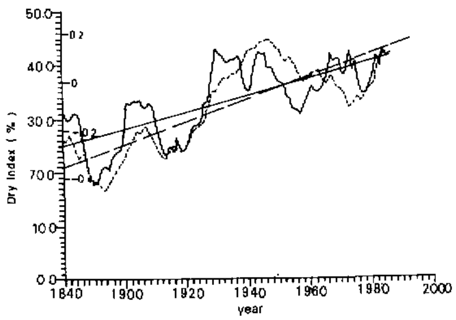

Fig.4. 10-year running means of drought index of China (solid line) superimposed with that of the Northern Hemisphere air temperature over land (dashed line).

Fig.3a is the result of Mann Kendall test for the drought index of China in the period of 1887–1986. The clear intersection of curve C_1 (solid line) and curve C_2 (dashed line) between the 5% levels of significance (dot–dashed line) localizes the abrupt change towards an aridity trend around 1922. Curve C_1 also indicates the existence of an increasing dry trend toward the end of the 1910′s. This abrupt feature can also be seen in other drought and flood indices as shown in Figs.1 and 2. The fact that the climate of China entered abruptly into a dry regime around 1922 provides a strong signal of regional climatic change.

V. SYNCHRONIZATION OF CLIMATIC CHANGE IN CHINA WITH THE GLOBAL TEMPERATURE CHANGES

It is very interesting to note that there is a good statistical relationship between the changes in the drought index in China and that of the global mean temperature, including the abrupt features of their evolution.

Fig.4. presents a curve of the Northern Hemisphere mean temperature over land (dashed line), superimposed by a curve of drought index of China (solid line) since 1880, showing a very close relationship between them: the increasing trend, the oscillation and the abrupt change around the early 1920′s. The peak period of global warming (around 1930′s to 1940′s) coincides very well with the peak period of drought development in China.

Fig.3b is a Mann Kendall test for the Northern Hemisphere air temperature over the land. This is a data set developed by Jones et al.(1986). A clear intersection of curve C_1 and curve C_2 at about 1921, which is located above the 5% level of significance, indicates an abrupt warming occurred at almost the same time with the abrupt change of the drought index of China (see Fig.3a).

The synchronization between the climate in China and the global temperature on decade scale provides a unique example showing how the regional climatic change in response to the global warming, no matter what are the causes of the global warming.

VI. GLOBAL PATTERNS OF PRECIPITATION ANOMALIES IN RELATION TO THE GLOBAL WARMING

In looking at further the relationship between the climatic change in China and global climate, Fig.5 presents a distribution of global zonal mean precipitation anomalies (based on the climatology of 1940–1979) during the peak period of warming (1930–1940), which is characterized by the following main features.

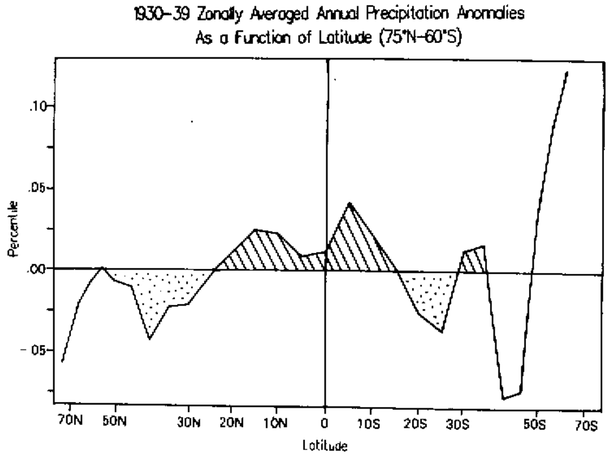

Fig.5. Zonally averaged precipitation anomalies for the period of 1930–1939 (reference to 1940–1979) (percentile).

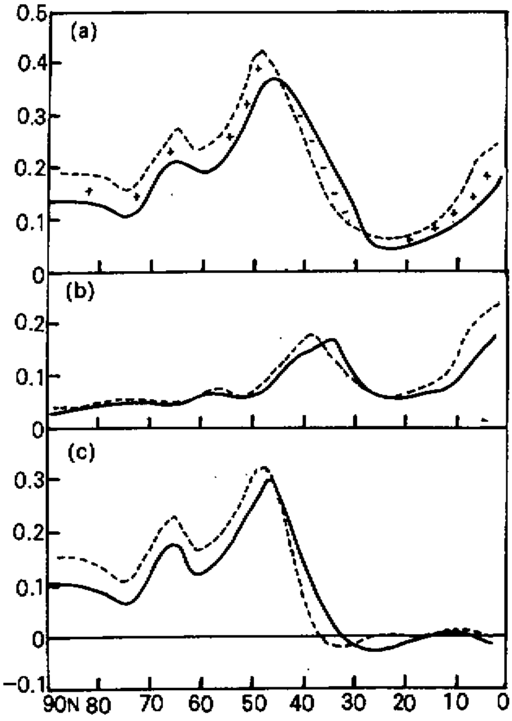

Fig.6. Latitudinal distributions of the zonal mean rates of (a) precipitation, (b) evaporation, and (c) precipitation minus evaporation in the continents of the sector model averaged. The zonal averaging is made over the continents. Solid and dashed lines indicate results from the $1\times CO_2$ and $4\times CO_2$ experiments, respectively (after Manabe, et al., 1983).

(1) an enhanced precipitation zone appears in the global tropics from 15°S to 25°N, especially along the positions of ITCZ in both hemispheres (10°N and 6°S). This feature implies the enhancement of ITCZ in relation to the enhanced rising branches of Hadley cells in both hemispheres during the warming period.

(2) a dry zone appears in the northern middle latitudes from 25°N to 55°N with a maximum negative departure along 40°N, where most of China is located. This feature indicates an enhanced descending branch relating to both the Hadley cell and the Ferrel cell. Therefore, the drought in China in relation to the global warming is only a regional manifestation of changing large-scale atmospheric circulation.

(3) another dry zone appears *in the southern subtropics from 15°S to 30°S, indicating* an enhanced descending branch of Hadley cell in the Southern Hemisphere. In this paper, we shall not discuss this feature and others in this hemisphere.

Whether the changes of global atmospheric circulation and relevant precipitation patterns during the warming period are related to the greenhouse effect of increasing atmospheric CO_2 concentration? Here some results of the climate model simulation are quoted to compare with the observations. Figure 6 is the latitudinal distributions of the zonal mean rates of (a) precipitation, (b) evaporation, and (c) precipitation minus evaporation over the continents of the Northern Hemisphere simulated by GFDL climate model. The solid and dashed lines indicate results from the $1\times CO_2$ and $4\times CO_2$ experiment respectively (Manabe et al., 1983).

According to this result (Fig.6a), there would be more precipitation in the tropics and less precipitation in the middle latitudes over the Northern Hemisphere land due to the greenhouse effect of increasing CO_2, very similar to the observed precipitation anomalies distribution during the peak period of global warming (1930–1940). Figs.6 (b) and (c) also indicate the dry conditions in the middle latitudes over the Northern Hemisphere land area. Does this result indicate the drought in middle latitudes of the Northern Hemispheric land area in the warming period is due to the greenhouse effect? If so, a continuation of middle latitude drought trend is expected for the next 50 to 100 years, and so does in China.

VII. CHANGES OF REGIONAL CIRCULATION OF PATTERNS IN RELATION TO THE ABRUPT CHANGE OF ARIDITY DEVELOPMENT IN CHINA

In addition to the background of global climate and the atmospheric circulation, the regional circulation pattern plays an important role in determining the regional climate.

Fig.7a gives the first rotated factor of EOF for the sea level pressure in the season of June, July and August and its factor scores for the period of 1899–1939, which explained 18.7% of the total variance. Focusing on the Eurasian and Pacific region, the changes of the western Pacific high, which is one of the dominant action centers in the eastern China during the rainy season,are shown clearly by the change of factor scores (see Fig.7b) around the 1923, when it changed from positive into negative. It indicates an enhancement of the subtropical high over the eastern Asia and the western Pacific around the early 1920's when China entered abruptly into an aridity regime. It should be noted that our time series are separated into two episodes, because of the discontinuity of the sea level pressure data between the two.

VIII. CONCLUSIONS

(1) There are plenty of evidences from the climatic records, hydrological records as well as the information of environmental change, to show a distinct aridity trend in China

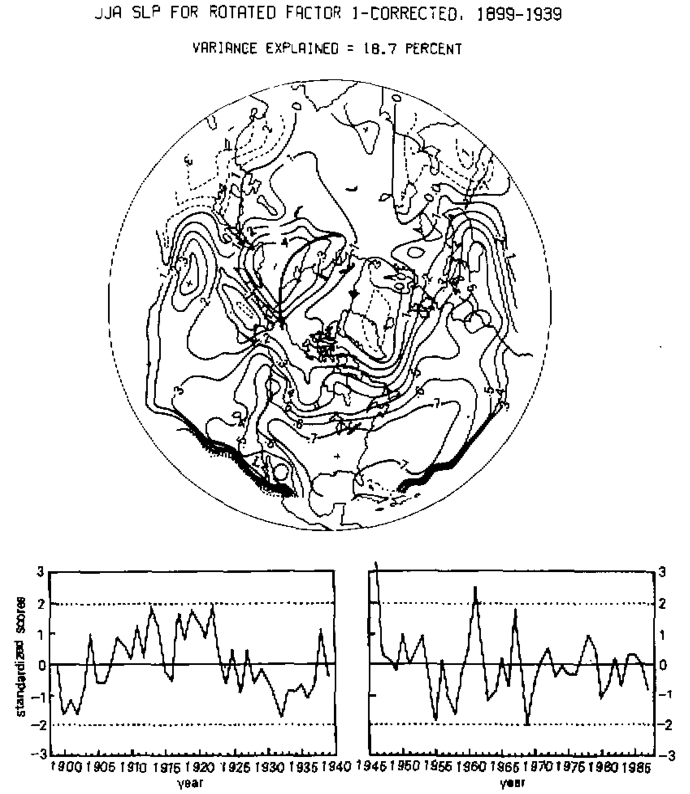

Fig.7. First rotated factor of EOF analysis for the sea level pressure of the Northern Hemisphere summer (June to August) (a) and its factor scores for the period 1899–1939 (b), which explains the 18.7% of total variance.

in the last 100 years.

(2) It is detected more quantitatively that the climate of China entered abruptly into the current dry regime around the early 1920's.

(3) The climate changes in China are closely linked with the changes of global temperature, in terms of their trend, the non–periodic oscillation and the abruptness features. The synchronization of abrupt change of climate in China with the abrupt warming of global temperature provides a good example of the regional response of climate to the global climatic change.

(4) In addition to the global scale impacts, the regional circulation patterns are also important to determine the regional climatic change. The change of subtropical high over the eastern Asia and the western Pacific is a crucial factor for the climatic change in China on decade scale.

(5) Although the observed zonal mean distribution of the precipitation anomalies during the peak period of warming is in consistent with that simulated under $4\times CO_2$, it is hardly accurate to derive the conclusion that the aridity trend in the middle latitudes as well as that

in China in the last 100 years could be attributed to the greenhouse effect before understanding the mechanism of this linkage.

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