Variations in droughts over China: 1951–2003

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[1] The Palmer Drought Severity Index (PDSI) was calculated by using monthly air temperature and precipitation in China during the period 1951 to 2003. For the country as a whole, there are no long-term upward or downward trends in the percentage areas of droughts (defined as PDSI < −1.0). However, significant increases of drought areas are found in North China. Most northern China (except western Northwest China) has experienced severe and prolonged dry periods since the late 1990s, when in some of the areas the extreme drought situations were unprecedented during the period of study. Since these regions are relatively dry areas, frequent drought stress in recent decades has become more serious. **Citation:** Zou, X., P. Zhai, and Q. Zhang (2005), Variations in droughts over China: 1951–2003, *Geophys. Res. Lett.*, *32*, L04707, doi:10.1029/2004GL021853.

1. Introduction

[2] Meteorological droughts are defined as abnormal periods of moisture deficiency relative to the long-term average over a given region [*Heddinghaus and Sabol*, 1991]. It is well known that droughts are one of the most damaging climate-related hazards to impact societies [*Woodhouse and Overpeck*, 1998]. IPCC [*Dai et al.*, 2001] report reviewed research results in variations of drought and wet spells under the global warming background. The Palmer Drought Severity Index (PDSI) suggests that secular global trends from 1900 to 1995 are relatively small for both severe drought (PDSI < −3.0) and wet area (PDSI > +3.0) statistics, while during the last two to three decades there have been some increases in the combined severe dry and wet areas over many ENSO-sensitive regions [*Dai et al.*, 1998]. *Dai et al.* [2004] show the global very dry areas (PDSI < −3.0) increased remarkably since the late 1970s due to decreased precipitation and increased temperature over these regions. China has also experienced warming climate in the 20th century [*Wang and Gong*, 2000]. Its mean surface temperature has a similar increasing trend with the global one. It is suggested that warmer climate would result in longer lasting and more severe drought due to enhanced evaporation [*Gregory et al.*, 1997] if without enough precipitation at the same time. For China as a whole, during the past half century annual precipitation has no significant trends, but decreasing trends in the number of rainy days and the longest durations of consecutive rainfall have been detected [*Zhai et al.*, 1999a, 1999b]. Also, the spatial distribution of precipitation trends across China is uneven [*Zhai and Zhang*, 2005]. In this study, we attempt to answer the following question: Have droughts become more long-lasting and more severe in China since 1951?

[3] Frequent severe droughts in 1997, 1999 to 2002 in many areas of northern China caused large economic and societal losses [*Zhang*, 2003]. In 2000, agricultural areas affected by droughts were estimated to exceed 40 million hectares. Because of the droughts, water shortage, desertification, and dust storms accompanied the drying climate over both the rural and urban areas. For instance, during 1972–1997, there were 20 years of which the Yellow River experienced drying-up (zero streamflow) episodes, and the earlier start time and longer periods of the drying-up have become more frequent since the early 1990s. The severe drought of 1997 in northern China resulted in a period of 226 days with no streamflow in the Yellow River, which is the longest drying-up duration on record. Furthermore, although there was a decreasing trend of dust storms over China from the mid-1950s to mid-1990s, frequent dust storms occurred in northern China from 1997 to 2002 [*Zou and Zhai*, 2004].

[4] These devastating drought conditions have been a concern of both the Chinese government and general public. Many studies have examined changes of humid or dry conditions in China during the recent decades. *Wang and Zhai* [2003] revealed an expanding trend of drought areas in northern China's main agricultural areas in the last 50 years using the China-Z index. Using a surface humidity index, *Ma and Fu* [2003] show a drying trend in North China and a wetting trend in some areas of Northwest China during 1951–1998. This study is primarily aimed at providing drought variation information over different regions within China and the whole nation during the past 53 years based on the PDSI.

2. Data and Methods

[5] In China, an index called the China-Z-index has been used since 1995 by the National Climate Centre of China as an operational real-time drought and flood monitoring tool. Applications and studies show that the China-Z-index is a good tool to define, detect and monitor droughts and floods in China [*Wu et al.*, 2001; *Wang and Zhai*, 2003]. However, the China-Z-index is derived solely from precipitation data and classified by the probability of precipitation cumulative frequencies. In this paper, considering its widespread use across the world and good reflection of soil moisture deficit or surplus, the PDSI is calculated to assess the drought variations in China. The PDSI is a useful proxy of both surface moisture conditions and streamflow [*Dai et al.*, 1998, 2004], and it is one of the most widely used indices in studying and monitoring meteorological droughts in the

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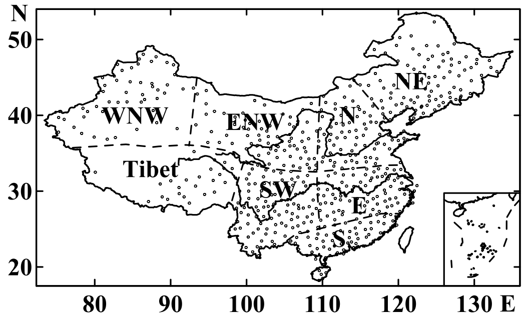

Figure 1. Locations of 606 stations and separate regions within China: Northeast, North, eastern Northwest, and western Northwest China are marked by NE, N, ENW and WNW respectively, they consist northern China. Southwest, East, and South China are marked by SW, E, and S respectively, these three regions consist southern China. Tibet plateau is marked by Tibet.

world [*Karl*, 1983; *Karl and Koscielny*, 1982; *Karl*, 1986; *Heddinghaus and Sabol*, 1991; *Dai et al.*, 1998; *Nkemdirim and Weber*, 1999; *Dai et al.*, 2004]. The PDSI usually ranges from about −6 to +6 with negative values denoting dry spells and positive values for wet spells, values of −0.5 to 0.5 are considered near normal.

[6] The PDSI was calculated over China by using monthly air temperature and precipitation for the period 1951–2003 at 606 stations covering most regions of mainland China (Figure 1). Stations with less than 40 years data have been rejected. The calibration period used is 1961–2000. For available water capacity (AWC), the soil-available-water-holding capacity map from *Guo et al.* [2001] was used.

[7] China has a vast territory, in which climate varies greatly from region to region. Dry climate generally dominates vast areas of western and northern China, while it is mainly semi-humid and humid in the eastern part of the country. Eastern China locates in the East Asia monsoon region, where both winter and summer monsoons are distinctly developed, and the climate events throughout the year are determined by the East Asia monsoon. For Eastern China, semi-arid or semi-humid climate dominates the northern parts of its territory with annual precipitation ranging from 200 to 800 millimeters, while the southern parts has a relatively wetter climate with annual precipitation ranging from 800 to 2000 millimeters. Individual regions discussed in this study are shown in Figure 1. For different regions within China and the whole nation, time series of annual dry areas (PDSI < −1.0) were calculated based on area-weighted average of station values in a 2° × 2° grid [*Zhai and Pan*, 2003]. It needs to clarify that a condition with PDSI < −1.0 may not represent droughts in many cases (e.g., during winter months when the soil is frozen in northern China). Furthermore, because of no data in western Tibet, time series of dry areas in this region only represent variations of its eastern part.

[8] To estimate the linear trends in droughts, the non-parametric Kendall's tau test is used and auto-correlation in the time series is removed before the trend estimation [*Kendall and Gibbons*, 1981]. The statistical significance of the trend is assessed at the 5% level.

3. Results

3.1. Variations of Drought Severity and Extent

[9] The percentage areas in drought conditions (PDSI < −1.0) for each year during 1951–2003 in China are showed in Figure 2a. The relatively large dry areas occurred in the 1960s, the late 1970s and the early 1980s, and the last 4–5 years. For China as a whole, secular trends of dry areas are small (0.50%/10 yr, Table 1) during the past 53 years. Figure 2b compares the areas with different drought severity with PDSI < −1.0, −2.0 and −3.0 respectively. It can be seen that droughts with different severity have similar variations with relatively large values of dry areas occurred in the 1960s and late 1970s. Although it is not evident for long-term trends in severe drought extent (PDSI < −3.0) (Table 1), severe drought areas have increased since the late 1990s (Figure 2b). The percentage areas of severe drought were persistently over 7% during 1997–2003 except for 1998 when central China and Northeast China were devastated by severe floods.

[10] Changes in dry areas (PDSI < −1.0) during 1951–2003 vary over different regions of China (Figure 3 and Table 1). Upward trends of dry areas (PDSI < −1.0) occur in North China (4.49%/10 yr). The dry areas in North China are relatively large during the last two decades with widespread droughts in this region frequently in 1997, 1999 to

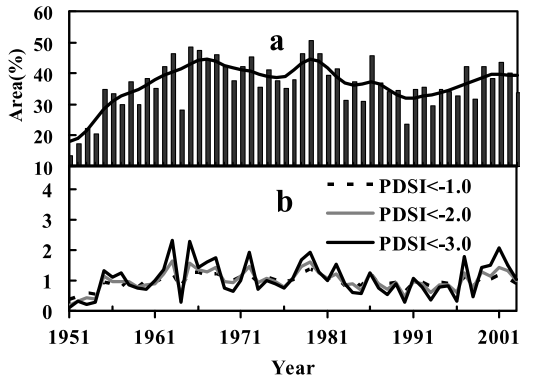

Figure 2. Time series of annual percentage areas in drought conditions over entire China during 1951–2003. a. Dry areas with PDSI < −1.0. The smooth curve is generated using an 11-point binomial filter. b. The anomalies (relative to 1971–2000 mean) of the percentage dry areas in China with PDSI < −1.0, −2.0 and −3.0 respectively.

Table 1. Trends (%/10 yr) of Drought Areas in Different Regions (See Figure 1) and Entire China During 1951–2003[a]

	Trend (%/10 yr)		
Region	PDSI < −1.0	PDSI < −2.0	PDSI < −3.0
NE	5.41	2.43	0.66
N	**4.49**	**2.89**	0.75
ENW	2.24	0.88	0.13
WNW	−3.96	−1.90	−0.88
E	−1.45	−0.61	0.00
S	−2.44	−0.62	−0.01
SW	0.16	0.38	0.23
Tibet	−3.35	−2.00	−0.96
All China	0.50	0.18	0.10

[a]The bold values are statistically significant at the 5% confidence level.

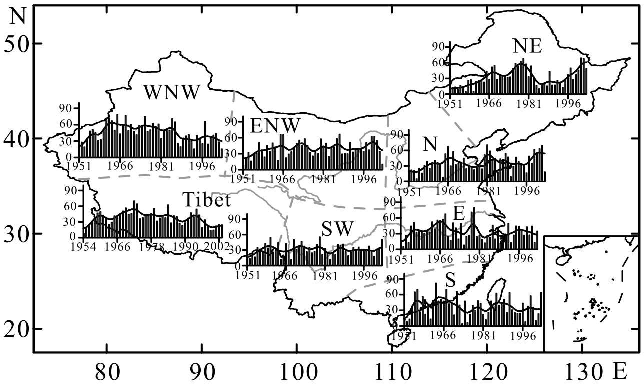

Figure 3. Time series of annual percentage areas (bars) in drought conditions (PDSI < −1.0) over different regions within China during 1951–2003. The smooth curves are generated using an 11-point binomial filter. Due to too few stations in early years, its calculation of drought areas is started from 1954 in Tibet region.

2002 (Figure 3). The drought areas from 1997 to 2002 are not the largest during the past 53 years in North China, while the successive severe droughts are unprecedented. Although statistically insignificant, increases of dry areas are also found in Northeast China (5.41%/10 yr) and eastern part of Northwest China (ENW, 2.24%/10 yr). During 1985–2003, the drying trend in Northeast China is striking, with a rate of 31.8% per decade. In 2001 and 2002, Northeast China experienced its most extensive droughts with nearly 70% of the region in drought conditions.

[11] No obvious trends in drought areas have been found in East China, South China, Southwest China, Tibet and western part of Northwest China (WNW) (Table 1 and Figure 3). Over many of these regions, however, there exist large multi-year to decadal variations in drought areas. For example, in East China, more extensive droughts occurred in 1960s and late 1970s, while drought stress seems relatively small after 1980. In western part of Northwest China, drought areas have decreased since the late 1980s (Figure 3).

[12] Trends in very dry areas (PDSI < −3.0) are statistically insignificant over individual regions and the whole country, although a meaningful increasing trend is found in North China with PDSI < −2.0 (Table 1).

3.2. Variations of Drought Duration and Frequency

[13] In addition to drought areas, variations in drought duration and frequency are also of interest. The longest drought duration (consecutive months with PDSI < −1.0) during 1951–2003 indicate drought conditions persist longer in northern China, compared to the south part of the country (Figure not shown). Most areas in North China, Northeast China, eastern Northwest China and eastern part of Southwest China experienced their longest drought durations in the recent two decades (Figure 4).

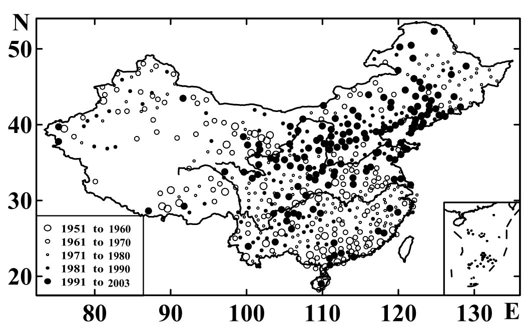

Figure 4. Decades when the longest drought duration (consecutive months with PDSI < −1.0) occurred during 1951–2003.

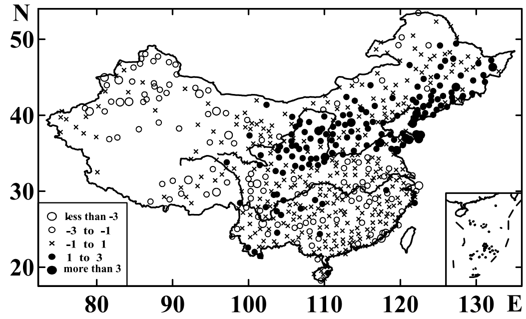

Figure 5. The difference of the annual mean number of drought months (PDSI < −1.0) between two periods: 1977–2003 minus 1951–1976.

[14] To reveal the changes in drought frequency, the differences of the annual mean number of drought months (PDSI < −1.0) between two periods of 1977–2003 and 1951–1976 are shown in Figure 5. Increased drought months have occurred mainly in North China, east and south part of Northeast China, east part of eastern Northwest China. Droughts hit these regions more frequently as the climate became drier in the recent two decades than before. Over most regions in southern China the difference in drought months between the two periods is small. In some stations in western Northwest China (WNW), decreased drought months have been detected. This result is consistent with the notion that Northwest China has become wetter during the last 50 years [*Wang et al.*, 2002]. Decreases in drought frequency can also be found in East China and west part of Southwest China.

4. Conclusions

[15] During 1951–2003, dry areas (PDSI < −1.0) in entire China show no secular trends. However, some significant changes have been detected over some regions within China, with increasing drought areas in North China.

[16] The successive large increases of dry areas (PDSI < −1.0) since the late 1990s in Northeast, North and eastern Northwest China are unprecedented during the past half century. The drought conditions in some regions in northern China have persisted for 4–5 years from 1997 to 2003. North China, Northeast China and eastern Northwest China have experienced more droughts in the recent two decades, which suggest that the climate has become drier in these regions. It should be noted that these drying trends are mainly in the places that usually receive less precipitation. Therefore, drought development is obviously a continuing threat to the ecosystem and agriculture in these regions. The results presented here are consistent with *Dai et al.* [1998, 2004], and support their notion that there has been increased risk of droughts since the late 1970s as global warming progress and produces both higher temperatures and increased drying.

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