Beijing Cloudiness since 1875

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(Manuscript received 7 July 1992, in final form 11 March 1993)

ABSTRACT

Two aspects of Beijing cloudiness are studied: its relationship to other climate parameters during the period 1951–1990 and the reconstruction of proxy values between 1875 and 1950. For the recent period, cloudiness varies with no apparent trend and is highly correlated with the total number of rain days ($r = 0.77$) and total sunshine duration ($r = 0.72$). Good correlation is also found with maximum surface air temperature, surface relative humidity, and total precipitation. While the correlation between cloudiness and solar radiation was large prior to 1976, the coefficient for the period 1976–1990 is much smaller. This decrease can be attributed to a negative trend in solar radiation, which is consistent with an observed decrease in visibility. Variations in Beijing cloudiness are closely related to those found over most of northern China, while little similarity is found with locations south of 35°N.

The large correlation between annual cloudiness and the total number of rain days between 1951 and 1990 was used in conjunction with the observed rain day record for the period 1875–1950 to construct a proxy cloudiness record for Beijing for the period 1875–1950. Comparisons between proxy cloudiness and available observations of surface air temperature and relative humidity reveal that the relationships are consistent with those found when observed cloudiness is compared with observed temperature and humidity data. On the century time scale, there is no clear trend in percent cloudiness. However, on the decadal time scale, there is a negative trend in cloudiness during the period 1880–1930 followed by a period of relatively constant values between 1940 and 1975.

1. Introduction

The climate of the earth is strongly influenced by the presence of clouds. Clouds have a significant impact on the solar and longwave radiation budget and are an integral component of the hydrologic cycle. The single most important scientific problem encountered in climate change research is the study of clouds and potential changes in cloudiness resulting from climate change (Houghton et al. 1990, 1992). Both theoretical and observational investigations are actively under way to address this issue (CEES 1992). However, an understanding of clouds and their impact on climate is complicated by a lack of long-term observational data and, as a consequence, the inability to study long-term cloud variations. The purpose of this paper is to investigate cloud cover characteristics at Beijing, China, for both century and decadal time scales.

In section 2 correlation analysis is used to determine functional relationships that exist between percent cloudiness and a set of independent variables for the period 1951–1990. Similar studies have been conducted for locations in the United States by Karl and Steurer (1990) and Angell (1990). The data used in this study are annual values of percent cloudiness, total rain days, total sunshine hours, maximum surface temperature, surface relative humidity, solar radiation reaching the surface, and precipitation. Continuous measurements of these variables in Beijing began in 1951. The correlation between annual cloudiness and the total number of rain days is found to be particularly high.

Because quantitative measures of Beijing cloudiness were not recorded prior to 1951, the long-term record of percent cloudiness must be reconstructed with proxy data. Section 3 discusses how rain day values from 1875–1950 (Beijing Weather Bureau 1982) are used to reconstruct the Beijing annual cloudiness proxy dataset for the same period. The proxy and observed cloudiness records are then compared with observed

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surface temperature and relative humidity data to determine if the relationships with the two cloudiness datasets are consistent. Finally, characteristics of long-term variations in Beijing cloudiness are examined.

2. 1951–1990 climate characteristics

A dataset recently compiled under the United States' Department of Energy and People's Republic of China's Academy of Sciences joint research program on the greenhouse effect (Tao et al. 1991; Riches et al. 1992) was used to study Beijing climate characteristics for the period 1951 to 1990. Monthly mean values of percent cloudiness, solar radiation reaching the surface (1958–1990), maximum surface air temperature, and surface relative humidity were used to calculate annual means (Table 1). Annual mean sunshine duration (hours per month), annual precipitation, and annual total number of rain days archives were also compiled and listed in Table 1. The time series for percent cloudiness (dashed line) is compared with those of the remaining climate parameters in Fig. 1. In this study a rain day is defined as a day when total precipitation is greater than or equal to 0.1 mm.

The data indicate the fact that during the period of study, there was no significant trend in percent cloudiness values over Beijing (Table 1, Fig. 1). Annual values ranged from a low of 41.5 percent in 1983 to a high of 56.4 percent in 1964. Mean cloudiness over Beijing for the period 1951–1990 was 47.4 percent. The 1960s tended to be a cloudier period, while the 1980s were less cloudy, particularly between 1980 and 1984 when consecutive low-cloudiness years were observed.

As may be expected, the correlations between percent cloudiness and the moisture parameters are large and positive. Comparisons between cloudiness and rain days, relative humidity, and precipitation result in coefficient values of 0.77, 0.57, and 0.52, respectively (Figs. 1a,b, and c). A very strong relationship was also identified between annual values of precipitation and the total number of rain days. Annual precipitation in 1959 was 1406 mm while the total number of rain days was 93. On the other hand, precipitation in 1965 was 262 mm and the total number of rain days was only 55.

In contrast, correlations between percent cloudiness and the parameters associated with solar radiation are negative. Comparisons between cloudiness, sunshine hours, and maximum surface temperature result in coefficient values of −0.72 and −0.63, respectively (Figs. 1d and 1e). An examination of Fig. 1f reveals that a negative trend in the total solar radiation reaching the surface occurred between 1975 and 1990. During the period 1958–1990, the correlation coefficient between percent cloudiness and solar radiation reaching the surface was only −0.26. A closer examination of the solar radiation data reveals that the low correlation between percent cloudiness and solar radiation is a result of changes in solar radiation values after 1975. For the period 1958–1975, the mean solar radiation reaching the surface at Beijing was 365.9 W m^{-2} and the correlation coefficient between total solar radiation and percent cloudiness was −0.81. However, for the period 1976–1990, the mean solar radiation value decreased to 326.1 W m^{-2} and the correlation coefficient between percent cloudiness and total solar radiation was only −0.40. Note that the amount of solar radiation reaching the surface depends on percent cloudiness, aerosol loading (e.g., visibility) and, to a lesser extent, the amount of trace gases (such as ozone) in the atmosphere. As can be seen in Fig. 1f, the negative trend in

TABLE 1. Beijing instrumental record of annual mean cloudiness C (%), sunshine amount SH (hours per month), maximum surface air temperature Tmax(°C), relative humidity RH (%), solar radiation reaching the surface S (W m^{-2}), total precipitation P (mm), and total number of rain days RD. The first five parameters are calculated from the monthly mean data; χ and σ represent the mean and standard deviation.

Year	C	SH	Tmax	RH	P	RD	S
1951	44.4	240.5	18.4	60.3	481.6	55	
1952	45.8	231.7	17.8	59.1	547.3	76	
1953	47.8	220.0	17.6	61.3	657.7	73	
1954	51.8	209.2	16.9	60.2	961.4	97	
1955	45.2	238.1	17.6	58.8	933.2	77	
1956	47.8	220.7	15.9	59.3	1115.7	94	
1957	47.6	247.4	17.0	55.6	486.8	78	
1958	46.9	239.3	17.7	55.9	691.9	76	347.4
1959	50.5	227.6	17.6	58.6	1406.0	93	345.4
1960	48.1	228.5	18.1	57.0	527.1	78	380.1
1961	47.4	226.6	18.8	58.1	599.8	80	368.4
1962	42.8	262.2	18.6	53.3	366.9	54	394.3
1963	48.4	241.9	18.4	55.7	775.6	68	377.6
1964	56.4	200.2	16.7	66.4	817.7	94	323.6
1965	42.6	259.6	18.9	57.5	261.8	55	381.1
1966	49.4	227.9	17.4	60.0	527.9	78	357.7
1967	48.8	226.1	17.4	58.8	593.4	85	371.0
1968	44.4	252.3	18.2	56.6	386.7	53	387.9
1969	49.3	204.6	16.1	59.4	913.2	84	347.4
1970	48.0	225.3	16.9	60.9	597.0	78	356.1
1971	46.5	235.2	17.3	61.3	511.2	63	370.8
1972	49.4	232.2	17.5	59.2	374.2	60	375.9
1973	50.3	222.8	17.1	63.4	698.2	93	358.2
1974	47.9	232.3	17.1	58.9	474.7	68	370.3
1975	45.9	242.1	18.4	59.3	392.8	52	373.4
1976	50.2	220.4	16.5	62.5	684.0	78	341.6
1977	48.9	229.2	17.3	61.8	779.0	73	341.0
1978	45.5	238.8	17.6	63.0	664.8	73	348.3
1979	49.2	222.3	17.1	63.3	718.4	71	331.9
1980	46.6	243.4	16.9	60.3	380.7	60	335.7
1981	45.1	233.7	18.1	51.2	393.2	59	339.5
1982	43.2	235.4	18.7	54.2	544.4	55	313.5
1983	41.5	237.0	18.9	53.6	489.9	45	342.7
1984	44.3	230.6	17.4	52.4	488.8	60	339.0
1985	51.6	209.3	16.7	56.8	721.0	78	302.1
1986	44.7	233.7	17.7	53.2	665.3	67	331.9
1987	48.0	219.3	17.8	58.3	683.9	74	311.8
1988	48.8	213.2	18.1	51.9	673.3	77	305.8
1989	47.2	218.9	18.6	53.8	442.2	60	306.5
1990	48.5	193.8	17.9	59.5	697.3	87	300.2
χ	47.4	229.35	17.6	58.3	628.2	72.0	347.8
σ	2.8	14.4	0.74	3.46	220.0	13.2	26.0

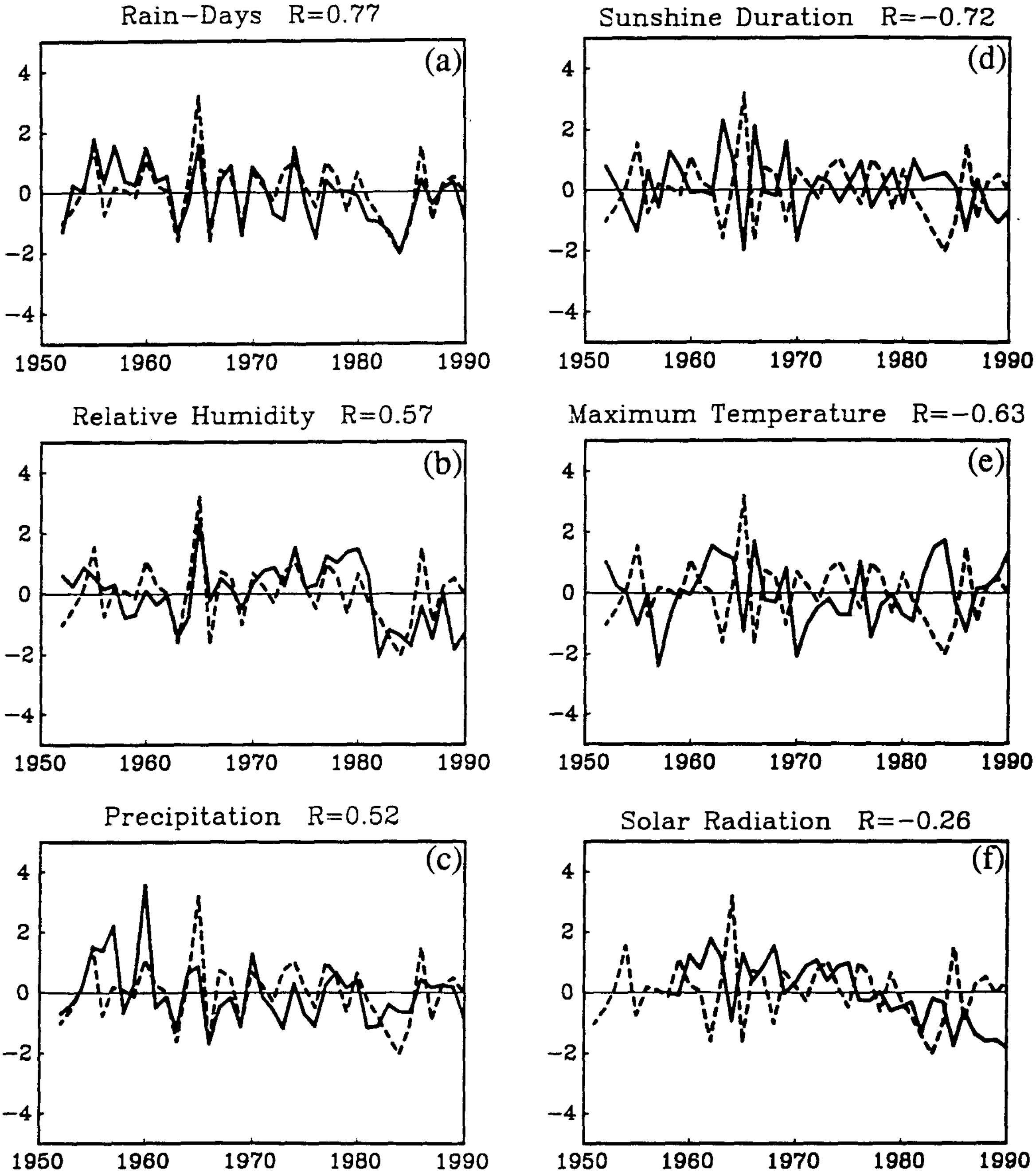

FIG. 1. Comparison between the total cloudiness (dashed line) and other indicated climate elements (solid line). Vertical coordinate is the number of standard deviations given in Table 1.

total solar radiation at Beijing began in 1975. An examination of visibility data for the period 1973–1989 indicates that values decreased during the period. This finding is consistent with the observed negative trend in annual solar radiation reaching the surface.

Finally, a stepwise multiple regression analysis between percent cloudiness and the remaining set of climate parameters was performed. An examination of the resulting R square scores reveals that values are not much greater than those for the comparison between cloudiness and rain days ($r = 0.77$; Fig. 1a).

The cloudiness characteristics observed at Beijing can be used to represent those observed over a large area. Correlation coefficients between percent cloudiness at Beijing and at a set of 60 stations throughout China (Tao et al. 1991) were calculated for the period

1951–1988 and mapped in Fig. 2a. For most of the stations located north of 35°N, the correlation is significant at the 99 percent level (dots). On the other hand, coefficient values are much smaller at the sites located south of 35°N (asterisks). The time series of annual percent cloudiness for northern China (mean of all stations located north of 35°N), southern China (mean of all stations located south of 35°N), and Beijing are shown in Fig. 2b. The Beijing time series is much more similar to that for northern China than it is to the southern China time series. While there is a slightly negative trend in percent cloudiness over southern China during this period, there is no apparent trend over either Beijing or northern China. Finally, the relatively strong influence of monsoon over southern China results in this region having a much larger value of annual percent cloudiness than either Beijing or northern China. All of these results suggest that the annual cloudiness characteristics at Beijing can be used to represent those over much of northern China.

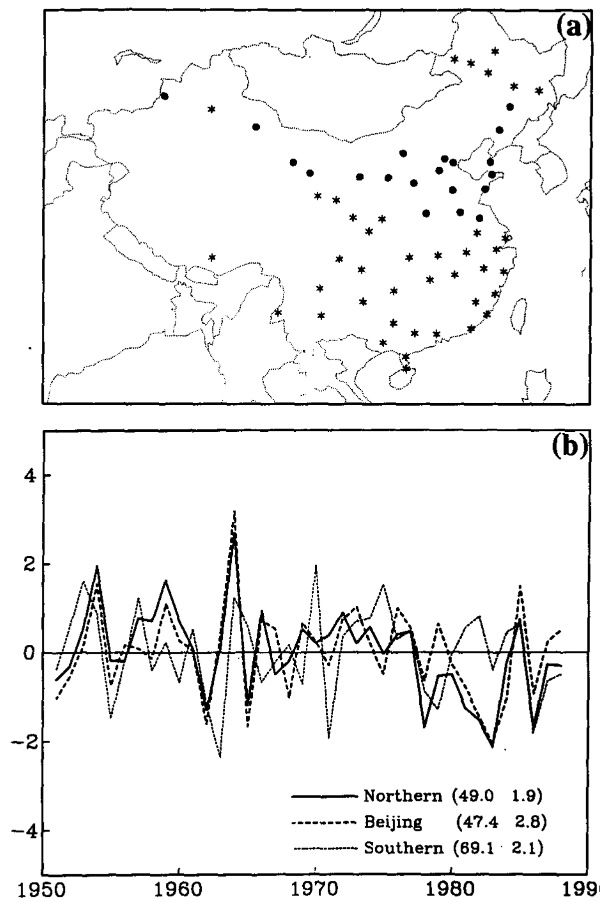

FIG. 2. Comparison of the total cloudiness for the period 1951–1988 between Beijing (dashed line) and values averaged over northern China (solid line) and southern China (dotted line) calculated based on the 60-station network listed in Tao et al. (1991). Here the northern/southern China is north/south of the Qin Mountain and Huai River (~35°N). Top panel shows the 60-station network with solid dots showing the significance at 99% level and the asterisks showing less significance. The values within the parentheses in the lower panel are the mean and the standard deviation for the respective regions.

3. 1875–1950 proxy cloudiness

Initially, rain day, relative humidity, precipitation, sunshine hour, maximum temperature, and solar radiation data were considered to reconstruct the cloudiness record. However, before 1951, measurements of humidity, sunshine hours, maximum temperature, and solar radiation were sparse. And, while relatively continuous instrumental precipitation data measurements began in Beijing in 1841, there are still several gaps in the record prior to 1951. The only climate parameter that has been measured continuously for a long period of time is rain days. Monthly rain day data extend back to 1875 (Beijing Weather Bureau 1982; Tao et al. 1991). Hence, the rain day record was used to construct the proxy cloudiness dataset for the period 1875–1950.

An examination of the percent cloudiness and rain day data for Beijing during the period 1951–1990 (Fig. 3) reveals that there is a positive correlation between the two variables during each season. However, seasonal characteristics of the correlation vary. During the summer (JJA), percent cloudiness is high and the range of rain day values is large. On the other hand, winter (DJF) values of percent cloudiness and rain days are much smaller. In addition, the correlation coefficients for the four seasons are all lower than the annual mean value (0.77; Fig. 1a). Therefore, the rain day archive will be used to reconstruct annual mean cloudiness for the period 1875–1950.

In order to reconstruct the cloudiness proxy dataset, a regression relation between percent cloudiness and rain days will first be developed for the period 1951–1990. Recall that the correlation coefficient between the two variables for this period is 0.77 (Fig. 1a). Annual rain day totals between 1875 and 1950 will then be inserted into the resulting regression equation to calculate annual percent cloudiness for the same period.

The regression relation between observed annual mean cloudiness, C, and the annual total number of rain days, R, for the period 1951–1990 (see Table 1) is

$$C = 47.4 + 0.166(\mathrm{R} - R), \qquad (1)$$

where R is the average annual number of rain days for the period. The reconstructed proxy annual percent cloudiness dataset for the period 1875–1990 as well as observed values between 1951 and 1990 are shown in Fig. 4. For the period 1951–1990, the proxy cloudiness represents well the observed cloud characteristics. On the century time scale, there is no obvious trend in annual percent cloudiness values over Beijing. However, there was a negative trend during the period 1880–1930. This was followed by relatively constant values

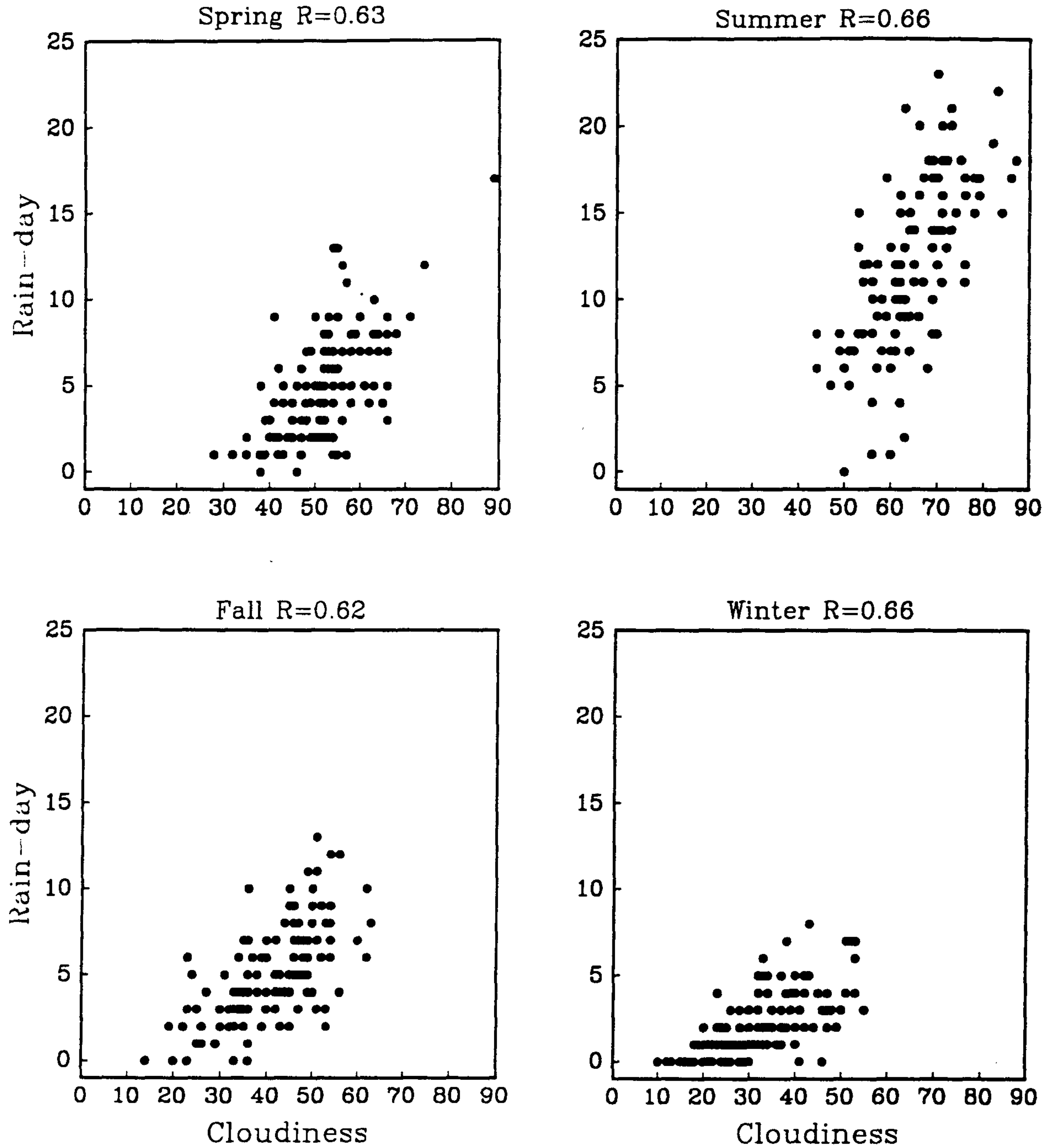

FIG. 3. Comparison of the mean cloudiness and the total number of rain days for spring (March–April–May), summer (June–July–August), fall (September–October–November), and winter (December–January–February).

between 1940 and 1975. The range of the percent cloudiness values between 1880 and 1930 is greater than that found between 1940 and 1975. The smaller range in values during the latter period is primarily a result of increases in local minima, while maximum values remained relatively constant. Note also that maximum cloud cover was measured in 1964, while the absolute minimum occurred in 1891. Other important features include relatively low percent cloudiness values during two periods extending from the late 1910s through early 1930s and the late 1970s through early 1980s.

In climate reconstruction, the issue of calibration must be addressed. It is very difficult to calibrate a proxy dataset with an observed record because, typically, there are few direct measurements of the relevant parameters

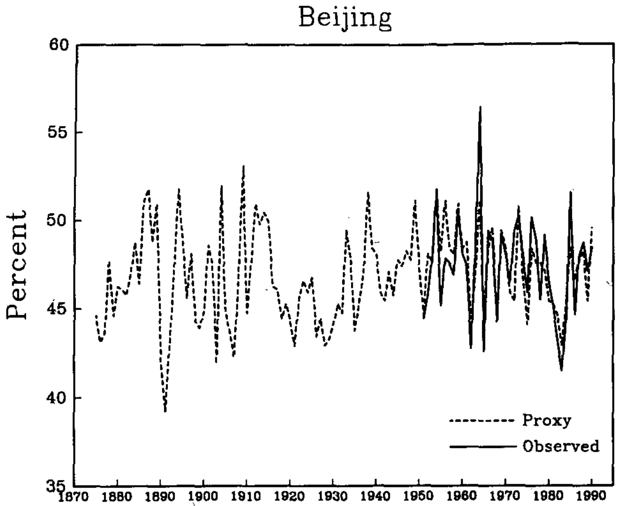

FIG. 4. Annual mean proxy cloudiness for the period 1875–1990 (dashed line) and the 1951–1990 observations (solid line).

used during the reconstruction period. For Beijing, observed relative humidity values have been recorded since 1875. Maximum, mean, and minimum surface air temperature records date back to 1916. However, each one of these datasets contains gaps during which measurements were not taken. Comparison of the proxy cloudiness and relative humidity time series (Fig. 5) shows that the two parameters are positively correlated. The same holds true when the instrumental records between 1951 and 1990 are compared (Fig. 1b).

Comparisons between the proxy cloudiness and observed maximum, minimum, and mean temperature time series, shown in Fig. 6, reveal that temperature is negatively correlated with cloudiness. In addition, proxy cloudiness is more highly correlated with maximum temperature than with either mean or minimum temperature. The calculated high negative correlation between proxy cloudiness and maximum temperature is consistent with the findings of high correlation between observed cloudiness and maximum temperature between 1951 and 1990 (Fig. 1e). Note that annual mean temperatures remain relatively constant during the first two decades of the record and then fluctuate afterward, with two local minima during 1956 and 1969 and a maximum during 1961. After 1969, the mean temperature steadily increased. The mean temperature during 1989 is the greatest over the entire period of record. There are also two periods during which trends are identified in the maximum and minimum temperature fields. During the period 1940–1953, there is a large negative trend in maximum temperatures while minimum temperatures remain relatively unchanged. On the other hand, between 1965 and 1990, there is a large increase in minimum temperatures,

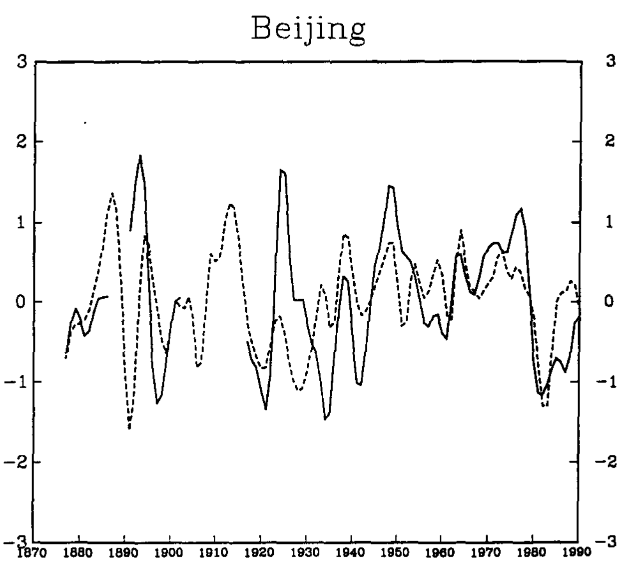

FIG. 5. Comparison between the annual mean cloudiness (dashed lines) and observed annual mean surface relative humidity in Beijing during 1875–1990. Ten-year running mean is used.

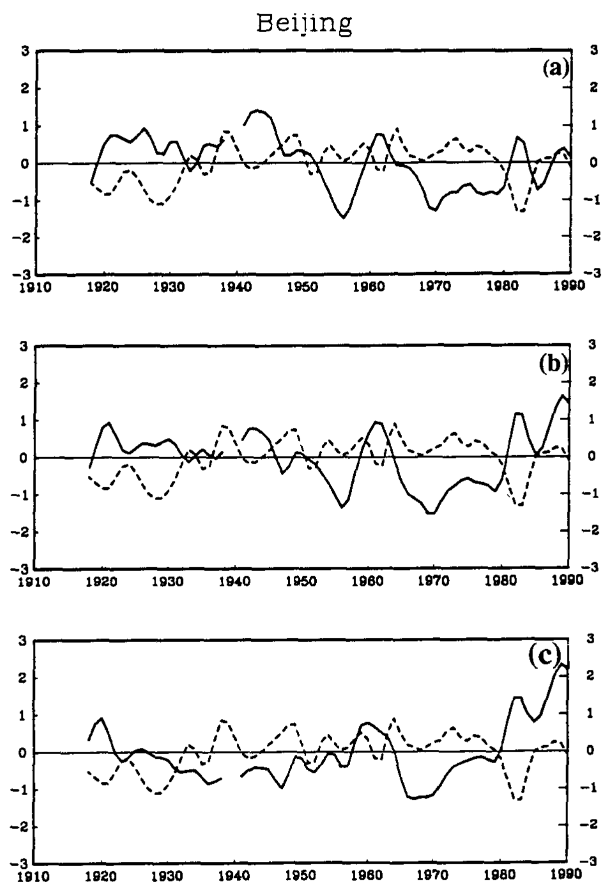

FIG. 6. Comparison between the annual mean cloudiness (dashed lines), and (a) maximum, (b) mean, and (c) minimum surface air temperature (solid lines) in Beijing during 1916–1990. Ten-year running mean is used.

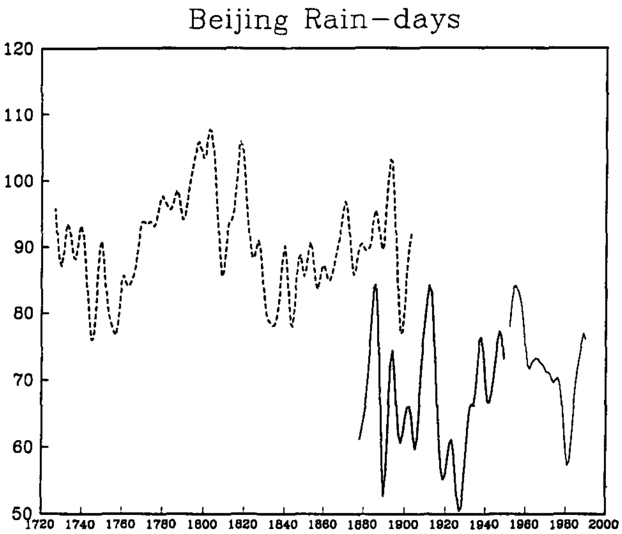

FIG. 7. Values of total number of rain days extracted from *Qing Yu Lu* (dashed line; Wang et al. 1992), and derived from precipitation measurements for 1875–1950 (solid line; Beijing Weather Bureau 1982) and for recent years (Tao et al. 1991).

while the positive trend in maximum temperatures is much smaller. The high correlation between cloudiness and minimum temperature during the first part of the 1980s is not found in the latter part of the decade.

In China, there exist many historical documents that contain qualitative descriptions of the weather. These documents provide a record of daily weather conditions, somewhat like today's weather reports, except that no instruments were used to take quantitative measurements. One of the most valuable documents is the *Qing Yu Lu* (*Clear and Rain Records*) kept in the National First Historical Archive at the Palace Museum in the Forbidden City in Beijing (Zhang 1982; Wang and Zhang 1988). For Beijing, the *Qing Yu Lu* were reported with little interruption during the period 1724–1903. These weather records have been used by researchers to reconstruct proxy temperature (Zhang and Liu 1987; Wang et al. 1992) and proxy precipitation (Feng 1980; Zhang and Wang 1989) datasets.

The rain day records used in this study were compared with those documented in *Qing Yu Lu.* Annual rain day time series for the periods 1724–1903 (*Qing Yu Lu*), 1875–1950 (Beijing Weather Bureau 1982) and 1951–1990 (instrumental) are shown in Fig. 7. The Beijing Weather Bureau (1982) and observational values are obviously much smaller than those in *Qing Yu Lu.* However, during the period when the *Qing Yu Lu* and Beijing Weather Bureau time series overlap (1875–1903), it can be seen that there is little difference in the occurrence of maximum and minimum values. The larger values in *Qing Yu Lu* are a result of the inclusion of days with precipitation amounts less than 0.1 mm in the definition of a rain day. Future research will be carried out to explore methods to correct differences between the *Qing Yu Lu,* the data in Beijing Weather Bureau (1982), and instrumental records so that the proxy cloudiness dataset can be further extended to 1724.

Acknowledgments. We thank Art Samel for editing the manuscript. The research was supported by the Environmental Science Division, Office of Health and Environmental Research, and the Department of Energy.

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