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NOTES AND CORRESPONDENCE

Climatology and Trends in Summer Precipitation Characteristics in Mongolia for the Period 1960–98

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Abstract

Changes in rainfall characteristics over Mongolia and adjacent regions during summer were examined for the period 1960 to 1998, using daily and monthly precipitation data for Mongolia, China and the former USSR. Climatologically, mean summer (June to August) total precipitation was greater in northern Mongolia, and tended to decrease toward the south and southwest. Summer total precipitation contributed more than 60% of annual precipitation in Mongolia. 'Wet days' is defined as a day exceeding precipitation more than 0.1 mm. The number of wet days was approximately 40 days in northern Mongolia, while the number of wet days was less than 20 days in the south.

Between 1960 and 1998, trends in summer total precipitation, the number of wet days in summer, and summer mean precipitation intensity were examined. The daily precipitation data were sorted into ascending order, and grouped into 10 classes which have an interval width equal to 10% of total number

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of wet days. Summer total precipitation increased in eastern and western Mongolia. Trends in heaviest precipitation class were also evaluated. The amounts of precipitation in the heaviest rainfall class, also increased in eastern and southern Mongolia and the Altai Mountains. The number of wet days increased over almost all of Mongolia. The frequency of relatively heavy rainfall events increased in eastern and southern areas, whereas during the same period weaker rainfall events became dominant in the northern part of central Mongolia.

1. Introduction

Long-term trend in seasonal and/or annual precipitation is studied on global and local scales (e.g., IPCC 2001). The trend was positive on the global scale, while the negative trend observed over large areas. Yatagai and Yasunari (1994; hereafter YY94) examined the summer total precipitation (hearafter PRJJA) trends for China and Mongolia during the period from 1951 to 1990. They found that a decreasing trend distributed over the arid and semi-arid region in Mongolia and northern China.

Temporal changes of precipitation totals are caused by both changes in precipitation frequency, and precipitation intensity during each event. Endo et al. (2005) found that summer total precipitation has an increasing trend, with increase in the precipitation frequency over northwest China during summer. On the contrary, summer total precipitation decreased, with a decrease in the precipitation frequency over north China. However, the precipitation intensity became more intense over both northwestern and north China. Further heavy precipitation events increased in northwestern China. Similar results were also found by Zhai et al. (2005). Sun and Groisman (2000) found that the precipitation frequency decreased, with an increase in frequency of heavy precipitation (greater than 20 mm in one day) in the southern part of Siberia during summer. However, changes in the precipitation frequency, the precipitation intensity and precipitation amounts of heavy precipitation events in Mongolia during summer have not been examined.

Recently, Mongolian daily precipitation dataset was provided by the National Agency for Meteorology, Hydrology and Environment Monitoring, of the Ministry of Nature and the Environment of Mongolia (hereafter NAMHEM). The newly available dataset gives an opportunity to examine changes in precipitation characteristics over Mongolia.

In this paper, we first describe climatology of summer precipitation characteristics in Mongolia and its adjacent regions. We examine long-term trends in PRJJA, the precipitation frequency, the precipitation intensity, and precipitation amount of heavy precipitation event in Mongolia, and its adjacent regions for summer during the period 1960–1998.

2. Data and method

2.1 Data

Monthly and daily precipitation data provided by the NAMHEM were used for description of climatology of summer precipitation characteristics, and examination of long-term trends in summer precipitation characteristics. We also utilized the daily precipitation data at 57 stations in China, as compiled by the China Meteorological Administration (CMA). Daily precipitation data at four stations in the former Union of Soviet Socialist Republics (USSR), from the Global Energy and Water Cycle Experiment (GEWEX) Asian Monsoon Experiment (GAME) Siberia baseline dataset (Ohata et al. 2003) and Global Daily Climatology Network Version 1, compiled by the National Climatic Data Center, National Oceanic & Atmospheric Administration, were also employed.

Tretiyakov-type gauges were used in Mongolia (Zhang Yinsheng 2004; Personal communication), and former USSR (Groisman et al. 1991). In China, the Chinese standard precipitation gauge was used for measuring precipitation (CMA 2003). Daily precipitation accumulation in Mongolia is from 00 UTC until 00 UTC in the next day (Zhang Yinsheng 2004; Personal communication). In China, the same accumulation time period was used for daily precipitation (CMA 2003). At former USSR stations, precipitation measurements were twice per day before 1966, and were then increased to four times per day (Groisman et al. 1991). In 1986, twice daily precipitation measurements were introduced again. These changes of observation practices in the former USSR, may introduce biases in the daily precipitation records. Although biases of gauge measurements, such as wind-induced gauge undercatch, wetting and evaporation losses, and underestimation of trace precipitation amounts (Goodison et al. 1998) may exist in the daily precipitation data, a bias-correction of the daily precipitation data was not applied here, because we do not have daily mean wind speed, daily mean temperature and trace record for Mongolia. In this study, 'wet day' is defined as a day exceeding precipitation more than 0.1 mm, since the daily precipitation data have a resolution of 0.1 mm.

Although precipitation data before 1960 are available for some stations in Mongolia, the data used in this study covered the period from 1960 to 1998, since the number of stations with the daily precipitation records increased in the late 1950's. For the Chinese and former USSR stations, the dataset covered the period from 1961 to 2000.

The monthly precipitation data for Mongolia, archived at the National Center for Atmospheric Research (DS579.0), the monthly precipitation data of the Global Historical Climatology Network, version 2 (hereinafter GHCN), and "The Monthly Climatic Data for the World", prepared by the National Climatic Data Center, NOAA (hereinafter MCDW) were also used as reference time series for quality control of the precipitation data.

The Extended Edited Cloud Report Archive, compiled by Hahn and Warren (1999), which covers the period from 1971 to 1996, was also used for preparing present weather code statistics, which are informative to describe the regional characteristics of dominant precipitation types.

2.2 Quality check procedure

Daily and monthly precipitation data were subjected to simple quality checks. The Mongolian monthly precipitation data (hereinafter DATA_M), were first compared with DSS579.0 for the period from 1960–1982 for each station. After 1983, DATA_M were compared with the GHCN. MCDW were used as reference data if monthly precipitation data in DSS579.0/GHCN were missed. Questionable DATA_M were then flagged.

Next, monthly data from the daily precipitation data for the Mongolian stations were compiled (hereinafter DATA_D). DATA_D and DATA_M were then compared, and any questionable values were flagged. The daily precipitation data were compared between the stations. Correlation on interannual timescales, between time series of DATA_D for each station, and other stations were calculated. The station with the highest correlation coefficient was chosen as the reference station for the stations considered. The correlation coefficients between the daily precipitation records for each summer at the two stations were calculated, and time series of the correlation coefficient was checked visually. Questionable daily precipitation data, were examined if the correlation coefficient of one summer differed markedly from that of other summers, and were discarded if the data obviously differed from the precipitation data at surrounding stations. For example, although the daily precipitation exceeded 50 mm at a station, the case where there is no rain is observed at surrounding stations. In the course of the quality check, 37 summer months in DATA_D were discarded. As one of the objectives of this study, was to evaluate long-term trends in precipitation characteristics, not to discuss interannual/interdecadal variations, we allowed up to three discarded summers for each station in DATA_D. The quality check procedure described above can easily pick up questionable very heavy precipitation. On the other hand, distinguish between '0 mm' precipitation amount, and 'lack of observation' is scarcely detected. However, questionable high precipitation amounts, and questionable very long dry spells, with the monthly precipitation data having a certain value were typical problems, in the daily precipitation data. Therefore, it seems that the problem of quality check procedure have limited effect on the present study. Although Karl and Knight (1998) used proxy data, produced by a gamma distribution, with a random number generator to fill missing daily precipitation data, for voided stations, in this study discarded data were not replaced.

Daily precipitation data at 20 stations in Mongolia, and 4 stations in the former USSR were kept. Frequency of discarded data was typically less than 5% at most of 20 Mongolian stations, and maximum discarded data frequency, was about 10% at one of the 20 sta-

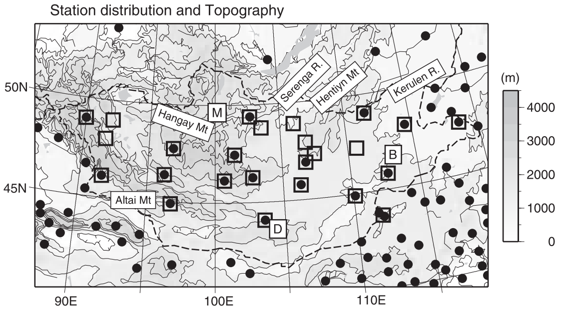


Fig. 1. Weather station distribution in Mongolia. Solid circles and open squares are the stations with daily precipitation data and monthly precipitation data, respectively. M, D and B are Moron (44231), Dalanzadgad (44373) and Baruun-urt (44305), respectively.

tions. The quality of the Chinese precipitation data had already been checked by Endo et al. (2005). DATA_M for 28 stations in Mongolia passed the quality check. The station distribution is shown in Fig. 1.

2.3 Classification and trend evaluation

Changes in PRJJA can be caused by a change in the frequency of precipitation events, a change in the precipitation intensity per event, or by a combination of both. All daily precipitation data were sorted into ascending order, and grouped into 10 classes for each station. Each of the 10 classes had an interval width equal to 10% of the total number of wet days in the analysis period. In this study, the lightest precipitation class was PR_C1, followed by PR_C2, PR_C3, and so on up to PR_C10, the heaviest precipitation class. This classification can describe relative contributions of the changes in each class to the changes in the seasonal total precipitation.

Figure 2 shows a histogram of daily precipitation at two Mongolian stations for the period 1960–1998. Most of the daily precipitation amounts, are less than 5 mm per day in these stations. On the other hand, precipitation larger than 20 mm per day, is infrequent during the study period. Since the lighter precipitation classes were consisted of many tied values, we will show only the results for PR_C10 in this study.

The nonparametric Mann-Kendall test (Kendall 1938), was applied to detect the precipitation trend at each station. Magnitude of trend was obtained, by applying the linear regression. A significance level of 0.05 was used throughout this analysis.

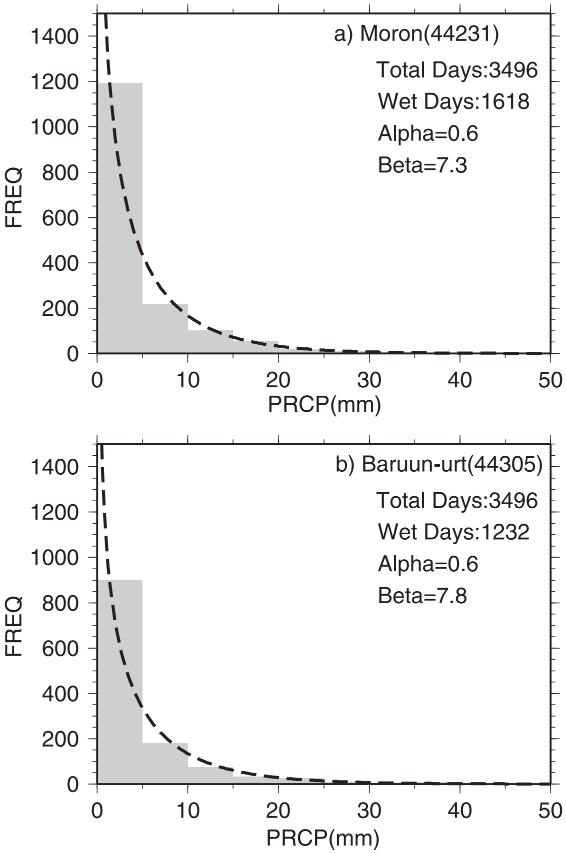


Fig. 2. Histogram of daily precipitation for the period of 1960–1998 at a) Moron (44231) and b) Baruun-urt (44305). Alpha and beta are the shape parameter and the scale parameter of the Gamma distribution (e.g., Wilks 1990).

3. Results

Climatologically PRJJA was more than 200 mm in northern Mongolia, and decreased southward and southwestward (Fig. 3a). PRJJA was less than 100 mm in southern and southwestern areas, and constituted more than 70% of the annual precipitation, in central and eastern Mongolia (Fig. 3b). These findings are similar to the results of Tuvendendorzh and Myagmarzhav (1985) and YY94, even though their study periods, were different from the present study. The number of wet days during

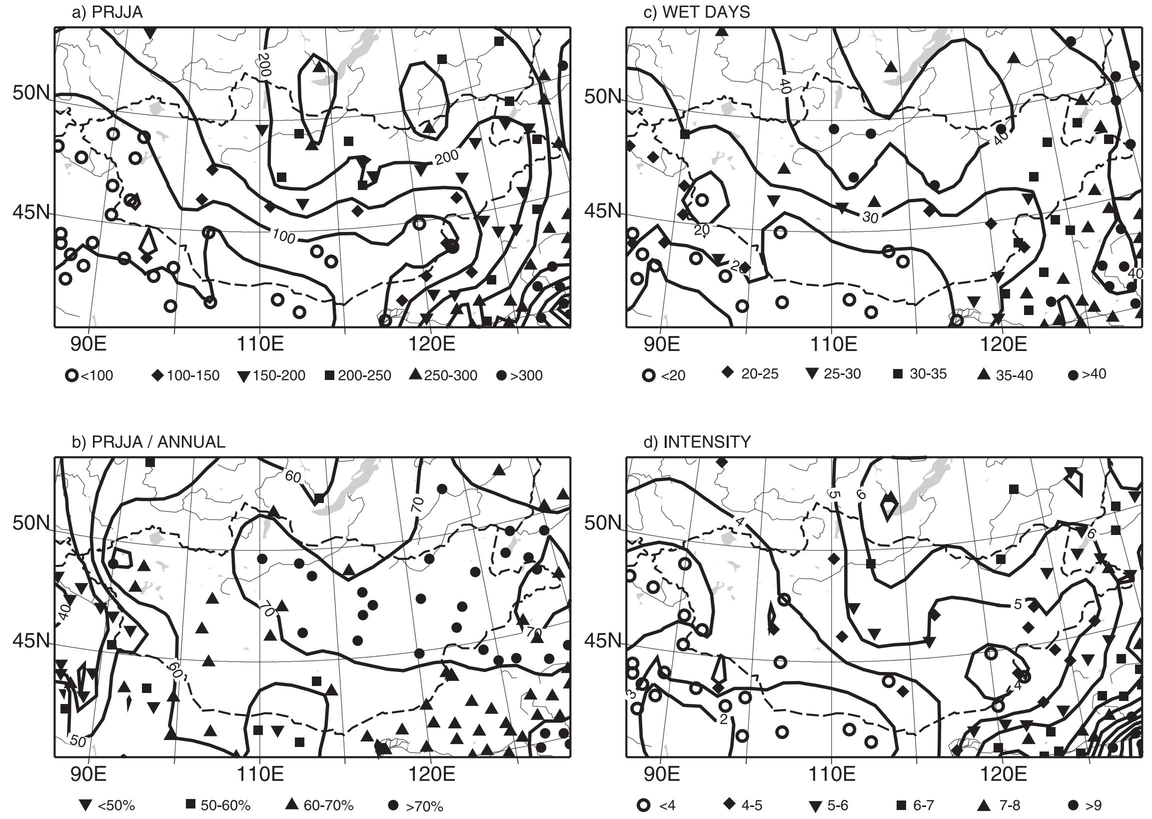


Fig. 3. Climatological distribution of a) summer total rainfall (Unit: mm), b) summer rainfall ratio to annual rainfall (Unit: %), c) number of wet days (Unit: days) and d) seasonal mean rainfall intensity (mm day^{-1}).

summer, is used as a proxy of the precipitation frequency. There were approximately 40 wet days in the Selenga River basin, and the Hentiyn Mountains (Fig. 3c), whereas there were less than 20 wet days in southernmost Mongolia and Gansu Province, China. We defined summer mean precipitation intensity as PRJJA divided by the number of wet days during summer. Summer mean precipitation intensity was approximately 5–6 mm day^{-1} in northeastern Mongolia, decreasing toward the south and west (Fig. 3d).

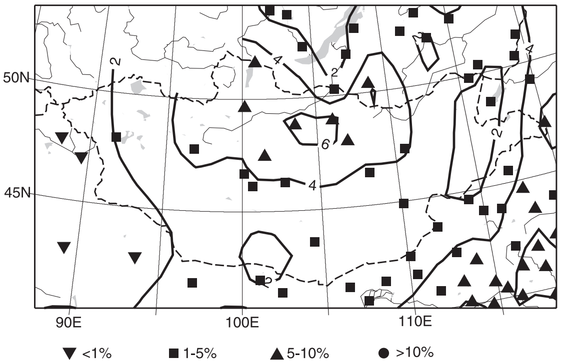
Figure 4a shows the climatological frequency of non-showery precipitation events (drizzle, rain, and snow). The frequency of non-showery precipitation observed was 6% in northern Mongolia, while non-showery precipitation was less frequent in southern Mongolia. The spatial distribution of showery precipitation frequency (thunder storms), is shown in Fig 4b. Showers were more frequent around Lake Baikal, and in Inner Mongolia, and were infrequent over the southern part of Mongolia.

The trend in PRJJA during the whole investigated period was generally upward in western and eastern Mongolia (Fig. 5a). However, only two stations had statistically significant trends. A downward trend was observed in central Mongolia, but it was not statistically significant.

The frequency of heaviest precipitation class (PR_C10), increased in eastern and western Mongolia (Fig. 5b). Statistically significant upward trends were observed at three stations in eastern Mongolia. The upward trends in the eastern and western regions correspond well with the trends in adjacent regions of China, whereas there are downward trends in the eastern part of the Hangay Mountains in central Mongolia.

The number of wet days increased in most of Mongolia (Fig. 5c). Statistically significant up-

a) Non-Showery



b) Showery

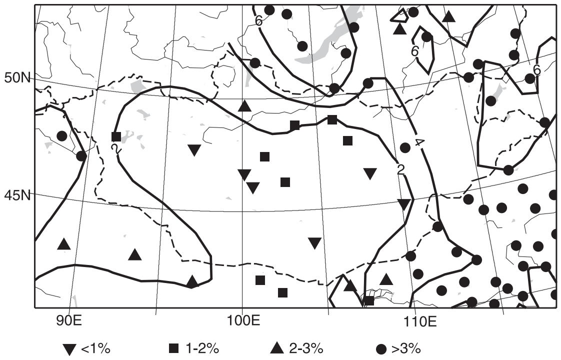


Fig. 4. Climatological distribution of a) frequency of non-showery precipitation and b) frequency of showery precipitation. Both frequencies were estimated from present weather codes from 1971 to 1996. Unit is %.

ward trends were observed in eastern Mongolia, and in the Altai Mountains. Although the number of wet days increased, both in the Altai Mountains and northwestern China, even if those regions have faced across the border, the trends in the number of wet days in Inner Mongolia are opposite to the trends in eastern Mongolia, which faced across the border. Precipitation measurement when weak precipitation occurs, is generally sensitive to the different observational practices, and the different gauges. Therefore the opposite trends would be partly caused by the different observational practices, and the use of different gauges. Impacts of different threshold value for defining wet days on the trends in the number of wet days were examined. The threshold value of 0.5 mm, and that of 1 mm were used. The examination showed that the opposite trends, in the number of wet days in eastern Mongolia and Inner Mongolia were also observed when the different threshold values were used. Thus the opposite trends in the number of wet days, were not caused by the different observational practices and the different gauges. Mechanism which produces the different trends in the number of wet days between eastern Mongolia and Inner Mongolia, is an issue we will examine in future research.

Changes in seasonal average precipitation intensity, were unevenly distributed (Fig. 5d). Two stations in central Mongolia had statistically significant downward trends, while seasonal average precipitation intensity tends to increase significantly at two stations in southern Mongolia.

The regional characteristics of trends showed notable differences between eastern Mongolia and the northern part of central Mongolia. Detailed descriptions of the trends in the two regions are warranted. At the weather station in Moron, located in the northern part of central Mongolia (marked as M in Fig. 1a), PRJJA decreased at a rate of about −15 mm per decade (Fig. 6a). PRJJA in the 1960s was about 200 mm, whereas in the 1990s it was about 150 mm. Conversely, the number of wet days increased from about 37 days in the 1960s to about 53 days in the 1990s. The median and third quartile of daily precipitation values for each summer tended to decrease; the average value for the third quartile of the 1960s was approximately 7.4 mm, dropping by approximately half by the 1990s (3.8 mm). Thus, more frequent, but weaker precipitation events became dominant at Moron.

At Baruun-urt in eastern Mongolia (marked as B in Fig. 1a), PRJJA increased significantly at the rate of 20 mm per decade, and the number of wet days increased slightly (Fig. 6b). Concurrently, larger third quartiles of daily precipitation for each summer were observed four times after 1989. The largest third quartile appeared in 1994, and higher third quartiles were observed in 1989, 1990, and 1998. The increase in the frequency of heavy precipitation events was the cause of the upward trend in PRJJA at Baruun-urt. Changes in the number of wet days were similar at both the Moron and Baruun-urt stations. However, the trends in heavy precipitation events at the two sta-

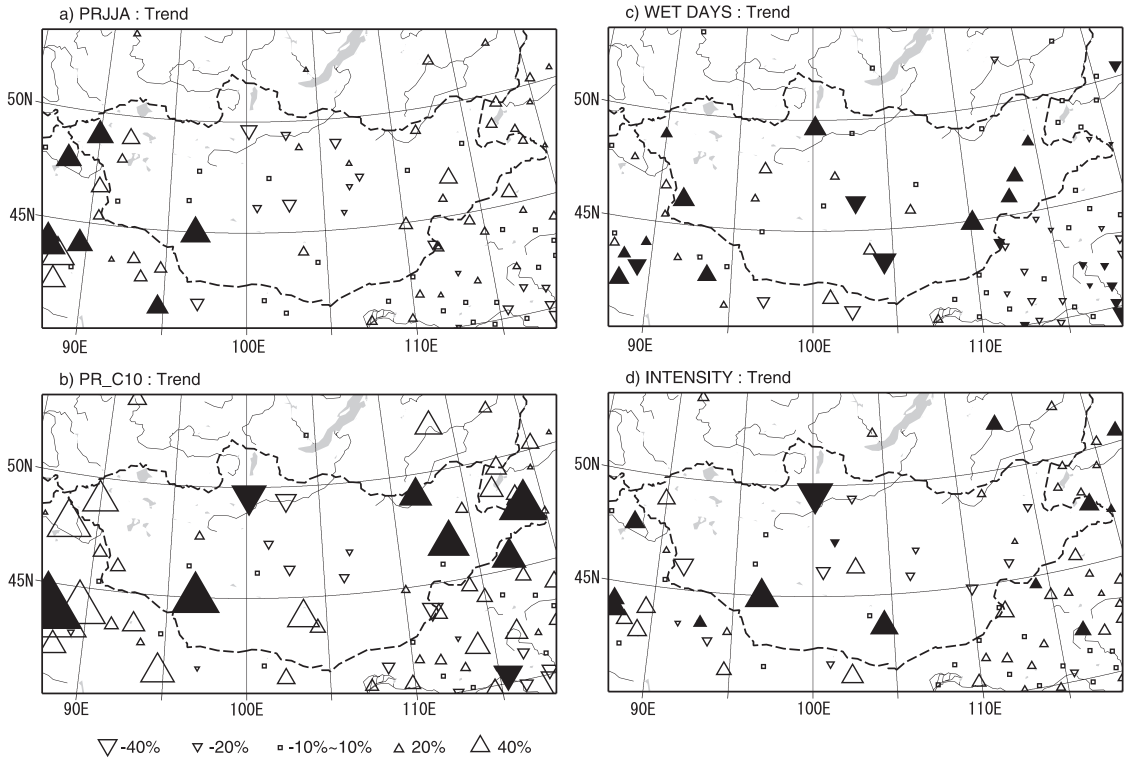


Fig. 5. Spatial distribution of trends in a) summer total precipitation, b) heaviest precipitation class, c) number of wet days and d) mean precipitation intensity. Trend is expressed as a ratio to its climatological value. Triangles and inverted triangles indicate increasing and decreasing trends larger than 10%, respectively. Small square is trend less than 10%. Solid marks indicate statistically significant trend tested by the Mann-Kendall test.

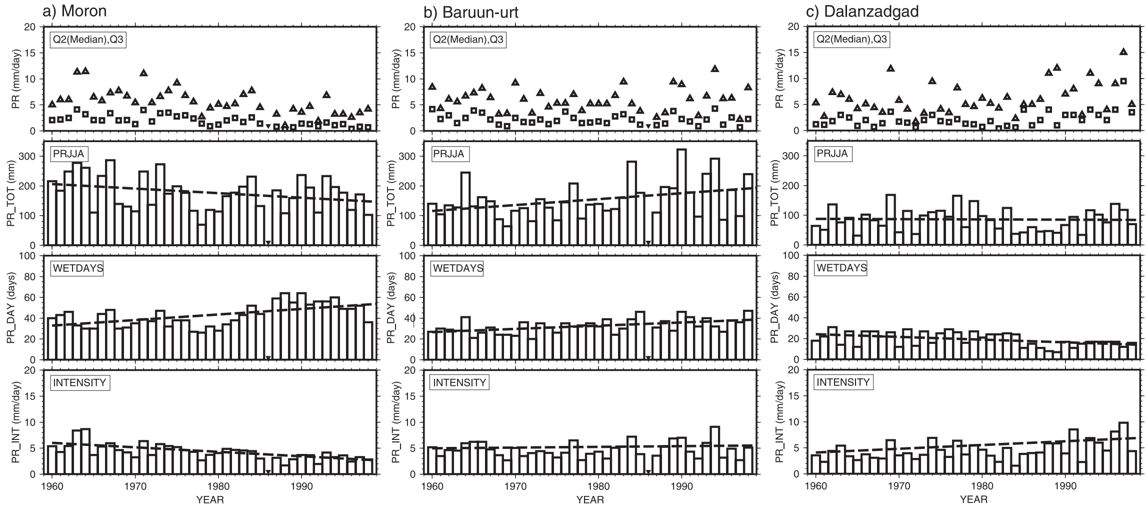


Fig. 6. Time series of summer total precipitation, numbers of wet days, seasonal mean precipitation intensity, and median (square) and third quartile (triangle) of daily precipitation data for each summer, respectively. Long-dashed line indicates linear trend. a) Moron (44231, Lat. = 49°38′N, Lon. = 100°10′E, Height = 1283 m), b) Baruun-urt (44305, Lat. = 46°41′N, Lon. = 113°17′E, Height = 981 m), and c) Dalanzadgad (44373, Lat. = 43°35′N, Lon. = 104°25′E, Height = 1465 m).

tions were opposite, and these changes regulated the changes in PRJJA.

Figure 6c indicates no trend in PRJJA at Dalanzadgad in southern Mongolia (marked as D in Fig. 1a). PRJJA were higher in the period from the mid 1970s to the early 1980s, and in the 1990s. However, PRJJA in the period from the mid 1980s, to the early 1990s were relatively small. Daily precipitation characteristics changed significantly with a downward trend in the number of wet days. The third quartile of daily precipitation each summer, became significantly larger after the late 1990s, up from a value of 7.9 mm in the 1990s, indicating that the frequency of heavy precipitation events has increased in recent decades.

4. Summary

Changes in precipitation characteristics over Mongolia and adjacent regions during summer were examined using daily and monthly precipitation data for Mongolia, China and the former USSR. Summer total precipitation values were higher in northern Mongolia, and tended to decrease toward the south and southwest. The contribution of summer total precipitation, to annual precipitation was more than 60%. 'Wet days' is defined as a day exceeding rainfall more than 0.1 mm. The number of wet days was approximately 40 days in northern Mongolia, while the number of wet days, was less than 20 days in the south.

Between 1960 and 1998, trends in summer total precipitation, the number of wet days in summer, and summer mean precipitation intensity were examined. The daily precipitation data were sorted into ascending order, and grouped into 10 classes which have an interval width equal to 10% of total number of wet days. Trends in heaviest precipitation class were also evaluated. Summer total precipitation increased in eastern and western Mongolia. The precipitation amounts in the heaviest rainfall class (PR_C10) also increased in eastern and southern Mongolia, and the Altai Mountains. In the same period, the number of wet days increased over almost all of Mongolia. In summary, the frequency of relatively heavy precipitation events increased in eastern and southern Mongolia, whereas relatively weak precipitation events became dominant in the northern part of central Mongolia. The increase in the number of heavy precipitation events in eastern and western Mongolia, corresponded well with the increase in the number of the heaviest precipitation events in Inner Mongolia and northwest China. The trends in the number of wet days are opposite, between eastern Mongolia and Inner Mongolia.

This study has described the regionality of changes in precipitation characteristics. The regional characteristics of precipitation systems and mechanisms, contributed to changes in heavy precipitation events should be further explored, with the aid of satellite image analysis and regional model development.

Acknowledgments

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