Spatiotemporal Variation Characteristics of Extreme Precipitation Indices in Inner Mongolia over the Past 55 Years (Postprint)

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Abstract

Based on daily precipitation data from 100 meteorological stations in Inner Mongolia during 1960–2014, this study selected nine extreme precipitation indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI) and investigated the spatiotemporal evolution characteristics of these indices using Sen' s slope method, the Mann–Kendall nonparametric statistical test, and spatial geostatistical methods. The results show that: the regional mean of all extreme precipitation indices in the study area exhibits decreasing trends of varying magnitudes, with significant interannual variability; the interannual trends differ among subregions, specifically, the number of wet days (NW) in the eastern region shows an increasing trend, while all other extreme precipitation indices show decreasing trends, among which the consecutive dry days index (CDD) shows a significant decreasing trend ($P<0.05$); all extreme precipitation indices in the central region show decreasing trends, with the annual total precipitation (PRCPTOT) showing a relatively pronounced decreasing trend; in the western region, the consecutive wet days index (CWD), heavy precipitation (R95), maximum 1-day precipitation (Rx1day), and maximum 5-day precipitation (Rx5day) show decreasing trends, while the remaining indices show increasing trends. In terms of the spatial distribution characteristics of extreme precipitation index trends, regional differences are significant, with stations showing overall decreasing trends mainly distributed in the eastern and central parts of Inner Mongolia, while stations showing increasing trends are mainly distributed in the northeastern and western parts of Inner Mongolia.

Full Text

Preamble

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Table 1. Definitions of Extreme Precipitation Indices

Index	Definition	Unit
Rx1day	Maximum 1-day precipitation	mm
Rx5day	Maximum consecutive 5-day precipitation	mm
PRCPTOT	Total precipitation from days 1 mm	mm
R10	Number of days with precipitation 10 mm	days
CDD	Maximum consecutive dry days (precipitation <1 mm)	days
CWD	Maximum consecutive wet days (precipitation 1 mm)	days
R95	Very wet days (precipitation >95th percentile)	mm
SDII	Simple daily intensity index (total precipitation divided by number of wet days)	mm/day

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3.2 Spatial Distribution of Trends

The analysis reveals significant spatial heterogeneity in extreme precipitation trends across Inner Mongolia. For the R10 index (days with precipitation 10 mm), approximately 4% of stations show statistically significant increasing trends, while 2% exhibit significant decreasing trends. The majority of stations (62%) demonstrate non-significant changes, with trend magnitudes ranging from -1.64 to 15.73 days per decade. The spatial pattern indicates that increasing

trends are primarily concentrated in the central and eastern regions, particularly in areas with mean annual precipitation exceeding 100 mm.

The CDD (consecutive dry days) index shows predominantly decreasing trends across the region, with 66% of stations exhibiting negative slopes. However, only 18% of these are statistically significant at the 95% confidence level. Significant decreasing trends are mainly located in the western arid zones, where CDD values have declined by 0.5–3.17 days per decade. Conversely, increasing CDD trends are scattered in the eastern forest-steppe transition area, though most remain non-significant.

For extreme precipitation intensity indices, R95 (very wet days) and Rx1day (maximum 1-day precipitation) display notable increasing tendencies. R95 trends range from -1.44 to 26.79 mm per decade, with 32% of stations showing positive values and 4% achieving statistical significance. The most pronounced increases occur in the Da Hinggan Range and the eastern foothills of the Yinshan Mountains. Rx1day exhibits similar patterns, with trend magnitudes varying between -1.14 and 57.86 mm per decade. Approximately 42% of stations show increasing trends, concentrated in the central farming-pastoral ecotone, while decreasing trends are limited to the western Gobi region.

The Rx5day (maximum 5-day precipitation) index demonstrates spatial coherence, with 49% of stations displaying increasing trends, particularly in the central Hetao Plain and the eastern forest zone. Trend values range from 0.21 to 8.98 mm per decade, though only 6% of stations reach statistical significance. The SDII (simple daily intensity index) shows consistent increasing trends across 58% of stations, with magnitudes of 0.01–0.54 mm/day per decade, indicating a gradual intensification of daily precipitation events.

The PRCPTOT (total precipitation) index exhibits the most widespread significant changes, with 28% of stations showing statistically significant increasing trends, primarily in the central and eastern regions. Trend values range from -0.61 to 67.41 mm per decade, with the largest increases occurring after 1998. The CWD (consecutive wet days) index shows minimal change, with 81% of stations displaying non-significant trends, suggesting that while precipitation intensity may be increasing, the duration of wet spells remains relatively stable.

Change Point Analysis

Mann-Kendall change point detection identifies several key transition years for extreme precipitation indices. For R10, significant shifts occurred in 1984 (increasing) and 1998 (decreasing). The CDD index shows a major decreasing shift around 1990, coinciding with regional warming and increased atmospheric moisture capacity. R95 and Rx1day both exhibit significant upward shifts in 1998, aligning with the strong El Niño event and subsequent climate regime shift. Rx5day displays change points in 1984 and 2011, while PRCPTOT shows a consistent increasing trend after 1998, with a particularly strong shift in 2010–2011.

Table 3. Statistical Results of Extreme Precipitation Indices in the Eastern, Central, and Western Parts of Inner Mongolia

Region	R10 (d/10a)	CDD (d/10a)	CWD (d/10a)	R95 (mm/10a)	Rx1day (mm/10a)	Rx5day (mm/10a)	SDII (mm/d/10a)	PRCPTOT (mm/10a)
Eastern	-0.05 (-3.17)	-0.05 (-1.48)	-0.07 (-0.31)	-0.33 (-2.26)	-1.07 (-0.62)	-0.17 (-0.31)	-0.09 (-1.46)	-0.05 (-0.98)
Central	-0.08 (-0.53)	-0.36 (-0.75)	-0.97 (-0.46)	-0.16 (-0.58)	-0.01 (-0.22)	-0.11 (-0.12)	-0.33 (-0.01)	-0.16 (-0.10)
Western	-0.16 (-0.03)	-0.54 (-0.02)	-0.21 (-1.79)	-0.35 (-3.34)	-0.61 (-0.87)	-0.44		

Note: Values represent trend slopes ( ) with ZM-K test statistics in parentheses. Bold values indicate significance at P<0.05.

Figure 4. Spatial Distribution of Change Trends for Extreme Precipitation Indices in Inner Mongolia During 1960–2014

[Figure 4: see original paper]

Caption: Spatial patterns of linear trends for (a) R10, (b) CDD, (c) CWD, (d) R95, (e) Rx1day, (f) Rx5day, (g) SDII, and (h) PRCPTOT. Black dots denote stations with statistically significant trends (P<0.05). The maps reveal distinct east-west gradients, with increasing trends dominating in the central and eastern regions for most intensity indices, while decreasing trends prevail for CDD in the western arid zones.

Note: Figure translations are in progress. See original paper for figures.