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# ANALYSIS OF LONG-TERM CHANGES IN PRECIPITATION OVER CENTRAL JAPAN BY UTILIZING DAILY PRECIPITATION SERIES FROM *KUNAI*, THE FORMER LOCAL OBSERVATION NETWORK

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*Abstract* Before the current local observation network of the Japan Meteorological Agency (JMA), i.e., Automated Meteorological Data Acquisition System (AMeDAS), the former local observation network, i.e., *Kunai*, was used. Data sets from *Kunai* observation network were utilized to obtain homogeneous high spatial density daily precipitation data over central Japan, from 1931 to 2021. This enabled us to use data from 106 stations to analyze, in detail, the regional variability and trends in precipitation. The results showed an overall increasing trend in the frequency of heavy rainfall and a decreasing trend in that of moderate rainfall; however, sub-regional and seasonal differences were observed.

**Keywords:** long-term change, precipitation, climate index

## 1. Introduction

The latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report states that the frequency and intensity of heavy precipitation events have increased since the 1950s in most land areas with high confidence (IPCC 2021). In Japan, the trend analyses of 51 surface stations in the entire country showed that the frequency of extreme precipitation has significantly increased, while wet days have decreased (Ministry of Education, Culture, Sports, Science and Technology (MEXT) and Japan Meteorological Agency (JMA) 2020). Nakaegawa and Murazaki (2022) detected the statistically significant increasing trends in daily heavy precipitation-relevant climate indices in several regions of Japan using data of these 51 stations and pointed out regional differences in their trends. Because the representative scale of observed precipitation tends to be smaller in space and time than that of temperature, homogeneous and high-resolution data series are necessary for precipitation trend analysis.

Otsuka *et al.* (2008; 2009) combined the data sets from the observations of the *Kunai*, the former local observation network of JMA (Fujibe et al. 2008), and those of the Automated Meteorological Data Acquisition System (AMeDAS) and constructed a long-term series of high spatial density daily precipitation data over central Japan from 1931 to 2006 (hereafter KA2006). Four homogeneity tests adopted by Wijigaard *et al.* (2003) were applied to the data series to evaluate homogeneity during

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the period, as well as continuity when AMeDAS stations replaced *Kunai* stations around in 1976. In the study region, significant increasing trends in heavy precipitation indices in some regions and decreasing trends in the monthly total during winter were observed. The significant decreasing trends in winter were conspicuous in the region along the Sea of Japan.

In this study, we added AMeDAS data from 2007 to KA2006 and extended the data series to 2021 to include the past 15 years during which global warming seems to have accelerated. We aim to investigate precipitation trends in the region using renewed data sets and to see whether there have been any changes to the trends observed in the previous study.

## 2. Data and methods

The study area is "the central Japan", which includes 26 prefectures across the southern Tohoku to the Kinki Region (Fig. 1). There were 76 *Kunai* stations in KA2006 until 2006, which were succeeded by AMeDAS stations in this area. Some stations had locational changes during 2007–2021. Hence, these stations were excluded from the study to avoid losing the homogeneity of data, and 55 *Kunai* stations of KA2006 were included in this study for trend analysis. We also included data from 51 JMA surface stations that started operating before 1941 in central Japan. Figure 2a shows the area and locations of the total 106 stations used in this study.

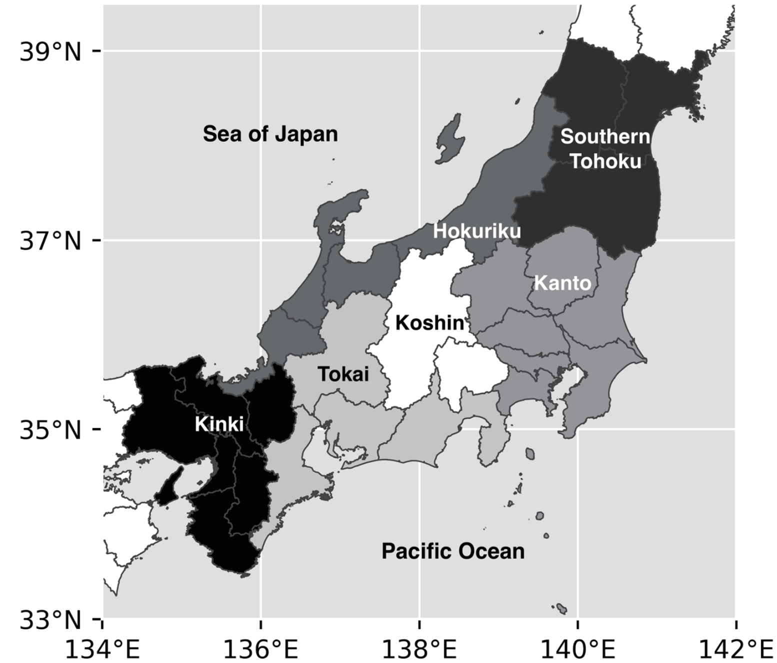


**Fig. 1** The study area, central Japan, and its sub-regions, southern Tohoku (Miyagi, Yamagata, and Fukushima), Hokuriku (Niigata, Toyama, Ishikawa, and Fukui), Kanto (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, and Kanagawa), Koshin (Yamanashi and Nagano), Tokai (Gifu, Shizuoka, Aichi, and Mie), and Kinki (Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama).

**Table 1** Climate indices for precipitation used in the trend analysis

| Indices | Description |
|---|---|
| PRCPTOT | Annual/seasonal total precipitation (PRCP) |
| R10/20/30mm | Annual/seasonal count of days when PRCP ≧ 10/20/30 mm |
| RX1/3/5day | The maximum consecutive 1/3/5-day value of daily PRCP in a year |
| R95/99p | Annual total PRCP when daily PRCP > 95/99th percentile |

First, we analyzed the time series of the monthly total amount of precipitation at all the stations to observe long-term changes from 1931 to 2021. The time series at an individual station were normalized using monthly values averaged over the years. We then investigated the climate indices for precipitation, as described in Table 1. We used the open-source web application, "Climpact" (https://ccrc-extremes.shinyapps.io/climpact/) to calculate these indices.

## 3. Results

### Local characteristics in long-term variability

The long-term precipitation variability in central Japan may differ according to locations and local climate because of a variety of geographical characteristics across these regions. We climatologically categorized the stations into groups by clustering the normalized time series of the monthly total precipitation from 1931 to 2021 using the Ward method. Examining the dendrogram, we divided all stations into four clusters. Each cluster seems to represent specific sub-regions as shown in Fig. 2. Cluster 1 includes stations located along the Sea of Japan, where precipitation in winter generally exceeds that in summer. Cluster 2 includes stations spread over the Pacific side of southern Tohoku, inland of Kanto and Yamanashi, which has less precipitation than the other groups and only one peak in autumn. Clusters 3 and 4 had abundant rainfall in summer and autumn. Cluster 3 includes stations in East Japan, where the autumn peak is slightly higher than the summer peak. ·

Figure 3 shows the averaged time series of the normalized monthly totals by cluster. We used a moving average window of 12 to extract annual seasonality from the original time series. The overall characteristics that are common to the four clusters are the relatively high positive anomalies in the early period, followed by low or negative anomalies in the mid-term, and uptrends in recent years. The peak timings were different among the clusters, suggesting that the amount of precipitation fluctuated in association with different meteorological disturbances.

### The trends in climate indices

Among the indices listed in Table 1, some showed statistically significant trends at stations in particular sub-regions. We mostly focused on indices regarding total precipitation and heavy rainfall frequencies, where significant trends were recognized well over several stations, as shown in Fig. 4. The statistical significance level of the trends was set at 5 %.

In winter (December, January, and February; DJF), PRCPTOT decreased at many stations along the Sea of Japan and several stations in Cluster 2 (Fig. 4a), although the annual PRCPTOT did not change so remarkably. R10/20mm showed a decreasing trend in the same season (Fig. 4b, c) at some stations in the coastal region of the Sea of Japan. R30mm also decreased at four stations in the same region (not shown).

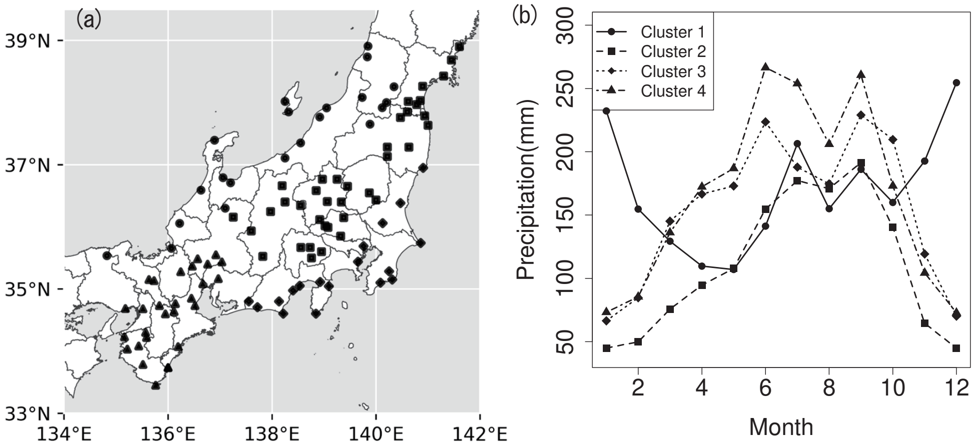


**Fig. 2** Stations in central Japan grouped by normalized monthly precipitation. (a) Distribution of stations. (b) Monthly total amount of precipitation averaged for the whole period (1931–2021) in Clusters 1 to 4. Circles, squares, diamonds, and triangles indicate stations that belong to Cluster1, 2, 3, and 4, respectively.

Annual R10mm showed decreasing trends throughout southern Tohoku and Kanto from eastern Japan to the coast of the Sea of Japan (Fig. 4d). In summer (Jun, July, and August; JJA), increasing trends for R10mm were apparent in the coastal region of the Sea of Japan, where there was a remarkable decrease in the winter (Fig. 4b, e). In autumn (September, October, and November; SON), many more stations showed decreasing trends for R10mm than in the other seasons (Fig. 4f).

There were widespread increasing trends in annual R30mm throughout central Japan (Fig. 4g). In summer, some stations in Tohoku and Hokuriku observed increase in R30mm, while some in the western part, such as the Tokai and Kinki regions, observed decreases in R30mm (Fig. 4i). The trends in spring (Fig. 4h) and autumn (not shown) at several stations in Tokai, Koshin and other regions also increased.

Increasing trends for R95p were widely detected from southern Tohoku to Kanto, Hokuriku, and at a few stations in the western part of the region (Fig. 4j). R99p and RX1day increased at some stations in Clusters 1 and 2 in the northern part of the region (Fig. 4k, l). Very few stations in Clusters 3 and 4 in the southern and western parts of the region on the Pacific side showed an increasing trend for these indices. For RX3day and RX5day, several stations in southern Tohoku and a few in other regions showed increasing trends (not shown).

## 4. Discussion

Otsuka *et al.* (2009) summarized the different characteristics of long-term precipitation time series in different sub-regions of central Japan. In the southern part of Tohoku and the coastal region of the Sea of Japan, the amounts have been high since around the 1980s and the late 1990s. In Kinki and Tokai in central-western Japan, and Kanto in the central-eastern Japan, they were high around the 1960s and the 1940s, respectively. We divided central Japan into four clusters in this study, and the similar long-term changes are shown in Fig. 3.

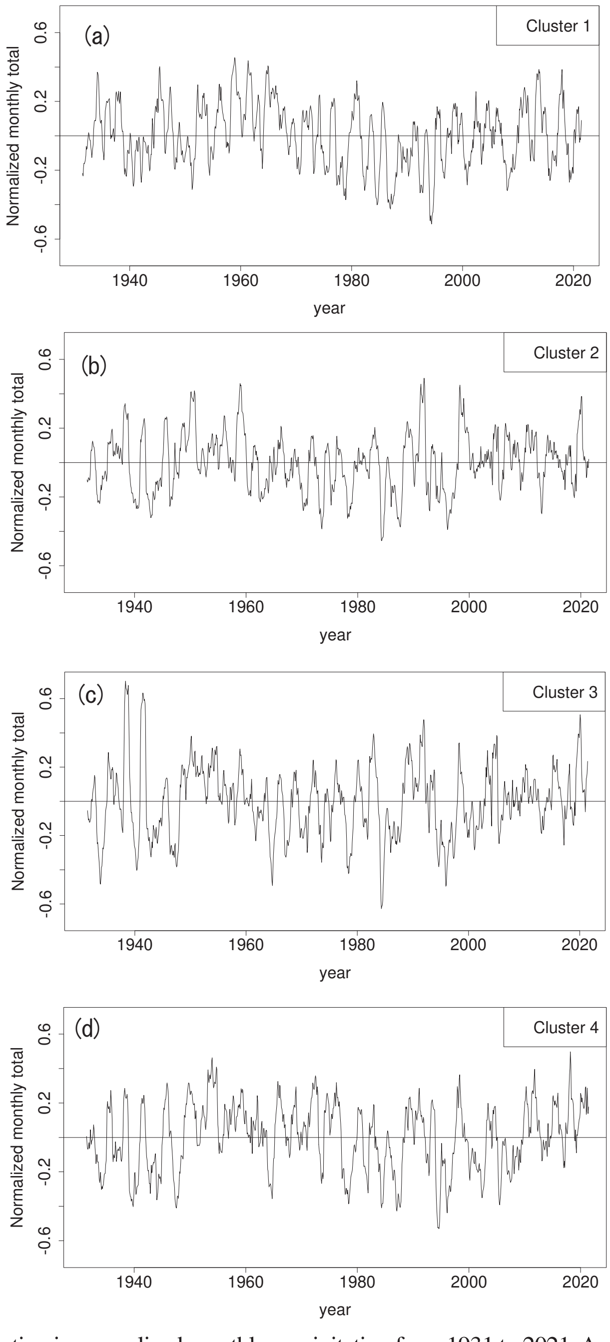


**Fig. 3** Long-term variation in normalized monthly precipitation from 1931 to 2021. Averaged over stations of (a) Cluster 1, (b) Cluster 2, (c) Cluster 3, and (d) Cluster 4 in Fig. 1.

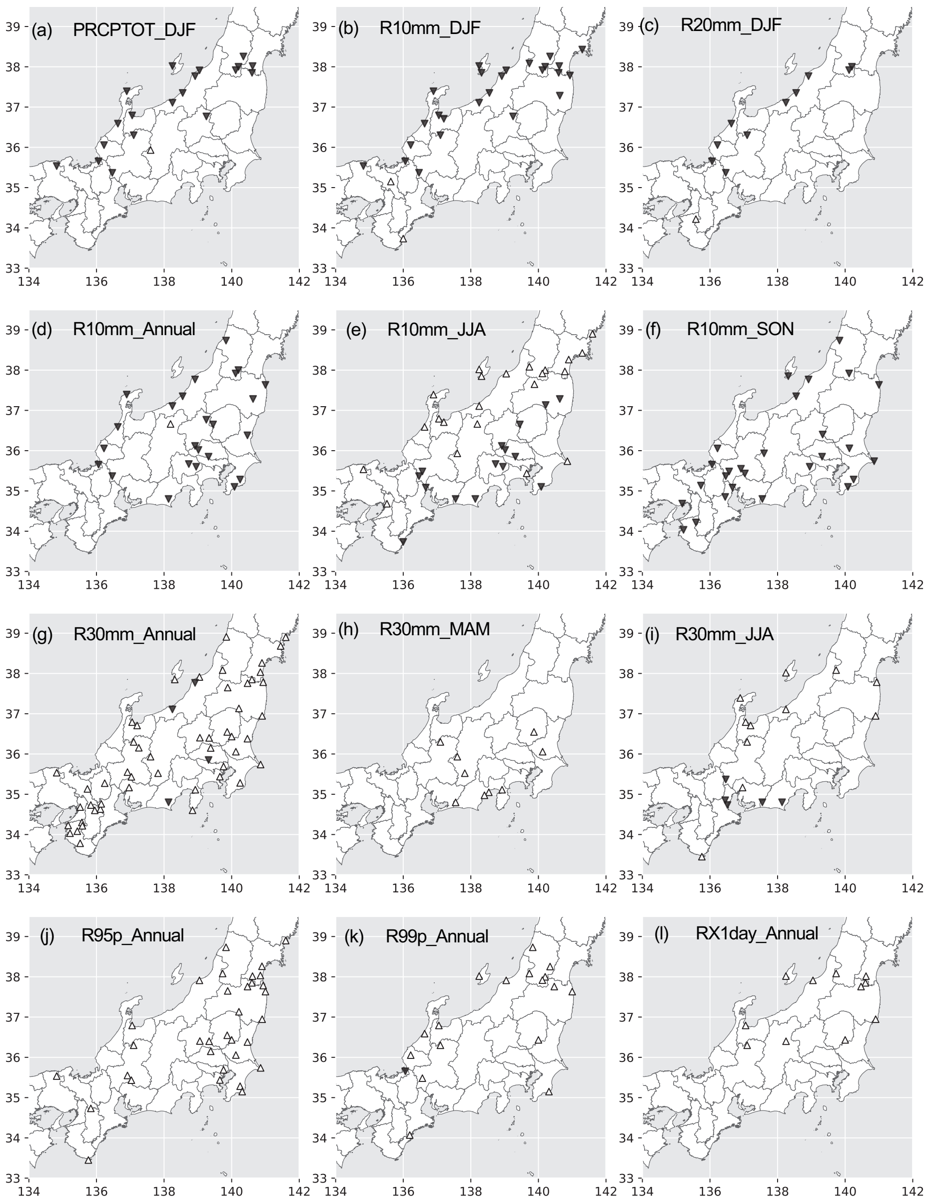


**Fig. 4** Trends in climate indices for precipitation at stations in central Japan from 1931 to 2021. White up-pointing and black down-pointing triangles represent increasing and decreasing trends, respectively. Climate indices are (a) RCPTOT, (b) R10mm, and (c) 20mm in DJF; R10mm in (d) annual, (e) JJA, and (f) SON; R30mm in (g) annual, (h) MAM, and (i) JJA; (j) R95p, (k) R99p, and (l) RX1day in annual.

Since the 2010s, the average precipitation anomalies over the 51 JMA stations were positive (MEXT and JMA 2020). This recent trend also seems apparent in the time series of Clusters 1, 3, and 4.

Next, we examined the results of the trend analysis (Fig. 4). The decreasing trends in winter widely detected in the region along the Sea of Japan and southern Tohoku agreed with the result from KA2006. These trends were consistent over the past 15 years. Otsuka *et al.* (2009) found the correlation efficiency of around 0.4–0.5 between the winter monsoon index (MOI) and monthly precipitation in the region. The strength of the winter monsoon around Japan may have partly accounted for the long-term variability in the winter precipitation in this region. They also detected decreases in winter precipitation at stations on the Pacific side, such as in the Kanto Region from KA2006, which were not observed in this study. Dry weather is usually dominant around Kanto in winter, but meso-lows that sometimes pass over the southern coast of the region bring rainfalls or snowfalls. The frequency of these phenomena in recent years could have reversed these trends.

There were many stations with decreasing trends in annual R10mm over central Japan. However, for annual R30mm and R95p, increasing trends were widespread. This may suggest that the frequency of heavy rainfalls is increasing, whereas that of moderate rainfalls is decreasing in central Japan overall. The differences in trends in different sub-regions and seasons were recognizable. In southern Tohoku, increasing trends in all heavy precipitation indices, including R99p and RX1day, are similar to the results of Otsuka *et al.* (2009). Because R10/20/30 mm in summer also showed increasing trends, heavy summer rainfalls may have occurred more often in this region recently. Some stations along the Sea of Japan also saw an increase in these heavy precipitation indices. Nakaegawa and Murazaki (2021) and Otsuka *et al.* (2009) detected the similar significant increasing trends for Hokuriku. Because winter precipitation has been decreasing in this region, they are likely to have experienced heavier rainfalls in summer. In the Kanto Region, annual R30mm and R95p showed increasing trends at many stations, which were not detected in the previous study. There were also many stations in the western part of the region where R30mm increased. It seemed that the heavy rainfall events that occurred in recent years contributed to the uptrends in those regions. Otsuka *et al.* (2009) pointed out that in the years when extremely high values of R99p were seen at many stations over central Japan, several disastrous heavy rainfall events occurred accompanied by typhoons or the Baiu front.

## 5. Conclusion

We constructed a long-term series of high spatial density daily precipitation data over central Japan from 1931 to 2021 by utilizing data sets from *Kunai*, the former local observation network of JMA. The number of stations with homogeneous data over the study area was 106, including surface synoptic stations. This enabled us to analyze the precipitation variability and trends in central Japan with better spatial and temporal coverage.

Decreasing trends in winter precipitation were widely detected at stations along the Sea of Japan and in southern Tohoku. However significant increasing trends in heavy precipitation indices were observed in the same regions, probably due to the increase in heavy rainfalls in summer. Heavy rainfall indices, such as R30mm and R95p, showed increasing trends at many more stations than those in the previous study from KA2006. This may suggest that the frequency of extreme precipitation in the region has increased over the past 15 years; however, a few stations showed decreasing trends. Investigating the causes of these recent increasing trends as well as sub-regional and seasonal differences should be the topics for future study.


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