Historical Drought Patterns Analysis Based on scPDSI over Japan

Tohoku University Student Member ○ Ke SHI
Tohoku University Member Yoshiya TOUGE
Tohoku University Member So KAZAMA

1. INTRODUCTION

Drought disasters are severe natural disasters in Japan that are also affected by climate change. Although drought generally has widespread impacts and the duration of drought can vary considerably, it is difficult to assess the drought homogeneous region comprehensively (Asong et al., 2018). Therefore, to identify the temporal and spatial characteristics of drought over Japan, this paper provides a spatiotemporal analysis for historical droughts patterns over Japan. The trends of precipitation, temperature, and potential evapotranspiration, which were the basis of drought index calculation, were first assessed. Then, drought characterized by the Self-calibrating Palmer Drought Severity Index (scPDSI) was investigated for the period 1960~2018. Subsequently, trends and patterns of drought were identified through the trend-free pre-whitening Mann-Kendall test (TFPW-MK) and distinct empirical orthogonal function (DEOF). This study is the first to identify homogeneous regions with distinct drought characteristics over Japan. Also, the results are beneficial for regional drought management over Japan.

2. MATERIALS AND METHODS

2.1. Data source

The study area is the whole of Japan. The 0.5° high-resolution gridded datasets of precipitation, near-surface temperature, potential evapotranspiration, and scPDSI were obtained from the Climatic Research Unit at the University of East Anglia. In this paper, the selected period ranges from 1960 to 2018. The scPDSI class is shown in Table 1. This scPDSI was presented by Wells et al. (2004), which was a variant of the original PDSI (Palmer, 1965) used to make the results from different climatic regimes more comparable.

2.2. Trend-Free Pre-whitening Mann-Kendall test

The Mann-Kendall (MK) test, which was proposed by Mann (1945) and modified by Kendall (1955), is widely used for analysing the change trends in hydrometeorological time series. However, this test requires that the data should be independent. Some hydrometeorological time series may usually display serial correlation. This will increase the probability that the MK test detects a significant trend, altering the magnitude estimate of serial correlation. To efficiently eliminate the effect of the serial correlation on the MK trend test, Yue et al. (2002) proposed the trend-free pre-whitening MK (TFPW-MK) test. Before the MK test, the time series is first detrended and pre-whitened. In this paper, we adopted TFPW-MK to analyse the time series trends. The specific details of TFPW-MK can be found in Yue et al. (2002).

2.3. Distinct Empirical Orthogonal Function

The empirical orthogonal function (EOF), which deals with temporal and spatial functions, is used to extract the spatiotemporal modes based on the data variance representations. The EOF analysis method can decompose the time-varying variable fields into the space function part (EOFs) that does not change with time and the time function part (principal components, PCs) that depends only on time. The distinct EOF (DEOF) analysis was subsequently introduced to overcome problems in the EOF analysis (Dommenget, 2007). In the DEOF, a continuous spectrum of spatial patterns resulting from a stochastic process can be represented by EOF modes, where some spatial structures will be more dominant than others. Based on the isotropic diffusion null hypothesis, the EOF modes (DEOFs) can be found by rotating the leading EOF modes, corresponding to the distinguished principal components (DPCs). These DPCs take up a large part of the total variance in all the variables in the original field, which is equivalent to the main information of the original field concentrated on a few main components. The higher the eigenvalues, the more typical the corresponding modes, and the more significant the contribution to the total variance.

3. RESULTS AND DISCUSSION

To better understand the drought trends in Japan, the variation characteristics of scPDSI were first analysed. **Fig. 1.** (a) shows the Z values of the scPDSI series at each grid point calculated by the TFPW-MK trend test. Significantly increasing drought trends (decrease in scPDSI) were observed in some western regions. Decreasing trends were found in the northwestern region, the western part of the central region, the partial area of the northeast region, and most of the northernmost region. And when the precipitation and the scPDSI trend analysis results were compared one mesh by one mesh (**Fig. 1** (b)~(c)), the trend analysis results of scPDSI varied with the change of precipitation trend.

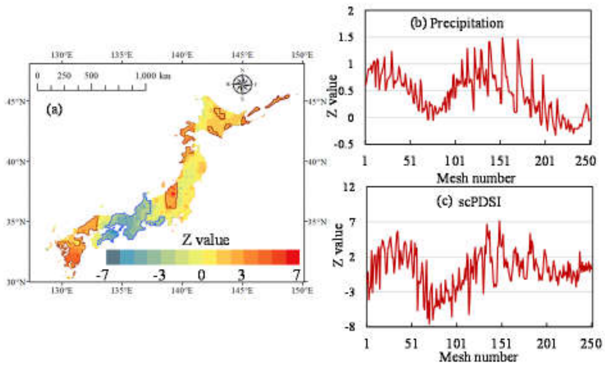

Fig. 1. (a) TFPW-MK trend analysis results over Japan (The blue contour indicates that Z value is less than -1.64; the red contour indicates that Z value is greater than 1.64). (b)~(c) Comparison of the trends of each mesh between precipitation and scPDSI

The DEOF calculation used the scPDSI time series of each grid point on the monthly scale. **Fig. 2** (a) and (b) displays the spatial partitioning results of the first two DEOFs. The explained variances in the first two DEOFs

Keywords: Drought, scPDSI, DEOF, Spatiotemporal patterns
〒980-8579 Tohoku University, 6-6-06 Aramakiaza Aoba, Aoba, Sendai, Miyagi, Japan. Tel & Fax: +81-22-795-7460

were 46.85% and 20.55% respectively, which meant that the DEOFs could explain approximately 67.40% of the total spatial wet/dry characteristics of Japan from 1960 to 2018. The first two had sufficiently explained variances to represent most of the wet/dry conditions in Japan.

The spatial distribution of DEOF1 illustrated that a high positive loading occurred in the western region at approximately 35°N (W region). This finding meant that the W region had similar drought characteristics from 1960 to 2018. Similarly, the spatial distribution of DEOF2 illustrated the common positive spatial behaviour of drought in most of the northernmost region near the Pacific (N region). However, the central region, western region, and most parts of the northwestern region showed common negative spatial behaviour, indicating that these regions showed the opposite drought characteristics as the N region. Notably, the two DEOFs were unable to represent all drought characteristics across the whole of Japan. For the corresponding drought temporal characteristics, the DPC scores are displayed in **Fig. 2** (c) and (d). The DPC1 scores showed a decreasing trend, which meant that the W region became drier. However, the N region was getting wetter.

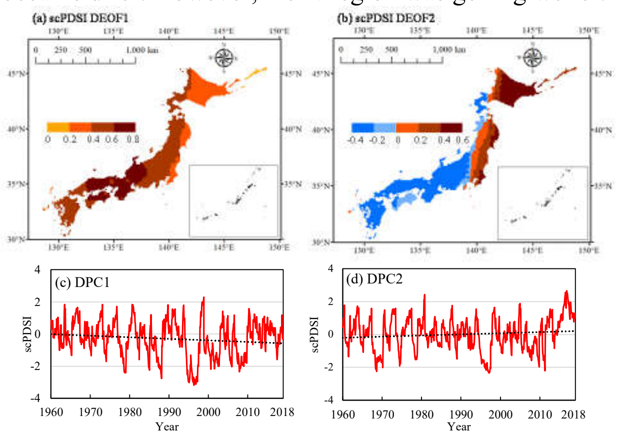

Fig. 2. First two DEOFs and DPCs for scPDSI. (a) DEOF1. (b) DEOF2 (c) DPC1 (d) DPC2.

Considering the ability of scPDSI to represent the water balance adequately, the analysis of combining drought with wildfires would further enhance the understanding of drought-induced natural disasters. Soil drought occurred most commonly in spring, which was also the season when wildfires frequently happen in Japan. Therefore, the comparison between the annual burned forest area in spring (March to May) with DPCs was extracted, as shown in **Fig. 3.** The burned area data (FDMA, 1995-2017) of the W region included the Ishikawa prefecture, Fukui prefecture, Gifu prefecture, Aichi prefecture, Shiga prefecture, Kyoto prefecture, Osaka prefecture, Hyogo prefecture, Nara prefecture, Wakayama prefecture, Tottori prefecture, Okayama prefecture, and Mie prefecture. The burned area data of the N region included the Hokkaido prefecture.

In a wet spring, when the scPDSI was positive, the burned area of western Japan was less than 100 ha. The three springs with severe wildfires, when the burned area was larger than 300 ha, were accompanied by drought events in which the scPDSI was less than -1. Although there were fewer wildfire occurrences in the N region than in the W region, these two regions followed a similar pattern. A total of six wildfires with burned areas of over 60 ha occurred in the N region. The scPDSI values corresponding to these six wildfires were all negative, and four of them experienced drought (scPDSI ≤ -1). When the scPDSI was more than 1, there were only six wildfire occurrences in the N region, and the burned area was less than 60 ha

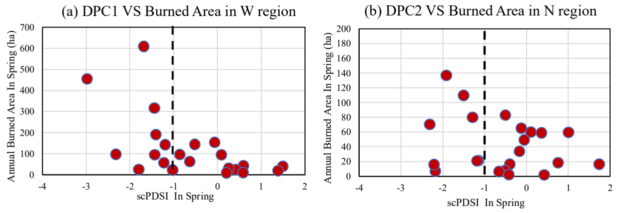

Fig. 3. Comparison of DPCs for annual burned forest area in spring (a) DPC1. (b) DPC2.

4. CONCLUSIONS

The main conclusions obtained from this paper are summarised as follows: (1) The trend analysis results of scPDSI varied with the change of precipitation trend. (2) DEOF was used to identify two major subregions of drought variability—the western region (W region) and most of the northernmost region near the Pacific (N region). The corresponding scores of DPC1 and DPC2 showed a trend of decreasing (increasing in drought) and increasing (decreasing in drought), respectively. (3) When scPDSI was less than -1, wildfires with larger burned areas were more likely to occur.

ACKNOWLEDGEMENT

This study was jointly supported by Grant-in Aid for Scientific Research (B), 2020-2023 (20H02248, Yoshiya Touge) and the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Exploratory Research, 2019-2021 (19K21982, So Kazama).

The authors declare no conflict of interest. All datasets utilized to perform this study are freely available on the internet.

REFERENCES

Asong, Z. E., et al. (2018). Historical drought patterns over Canada and their teleconnections with large-scale climate signals. Hydrology & Earth System Sciences 22.6.

Dommenget, D. (2007). Evaluating EOF modes against a stochastic null hypothesis. Climate dynamics 28.5, 517-531.

Fire and Disaster Management Agency, Fire report, 1995-2017.

Kendall, M. G. (1955). Rank Correlation Methods.

Mann, H. B. (1945). Nonparametric Tests Against Trend, Econometrica, 13.3, 245–259.

Palmer, W.C., (1965). Meteorological Drought, Office of Climatology U.S. Weather Bureau, Washington, D.C.

Wells, N., et al. (2004). A self-calibrating Palmer drought severity index. Journal of Climate 17.12, 2335-2351.

Yue, S., et al. (2002). Applicability of prewhitening to eliminate the influence of serial correlation on the Mann-Kendall test, Water Resources Research. 1–7.