

Statistical Properties of Effective Drought Index (EDI) for Seoul, Busan, Daegu, Mokpo in South Korea

Jong-Hyeok Park^{1,2}, Ki-Beom Kim^{1,3}, and Heon-Young Chang^{1,3}

¹Department of Astronomy and Atmospheric Sciences, Kyungpook National University, Daegu, Korea

²Korea Meteorological Administration, Seoul, Korea

³Research and Training Team for Future Creative Astrophysicists and Cosmologists (BK21 Plus Program), Kyungpook National University, Daegu, Korea

(Manuscript received 4 September 2013; accepted 2 March 2014)

© The Korean Meteorological Society and Springer 2014

Abstract: Time series of drought indices has been considered mostly in view of temporal and spatial distributions of a drought index so far. Here we investigate the statistical properties of a daily Effective Drought Index (EDI) itself for Seoul, Busan, Daegu, Mokpo for the period of 100 years from 1913 to 2012. We have found that both in dry and wet seasons the distribution of EDI as a function of EDI follows the Gaussian function. In dry season the shape of the Gaussian function is characteristically broader than that in wet seasons. The total number of drought days during the period we have analyzed is related both to the mean value and more importantly to the standard deviation. We have also found that according to the distribution of the number of occasions where the EDI values of several consecutive days are all less than a threshold, the distribution follows the exponential distribution. The slope of the best fit becomes steeper not only as the critical EDI value becomes more negative but also as the number of consecutive days increases. The slope of the exponential distribution becomes steeper as the number of the city in which EDI is simultaneously less than a critical EDI in a row increases. Finally, we conclude by pointing out implications of our findings.

Key words: EDI, drought, solar activity, data analysis, climate change

1. Introduction

Droughts are among the greatest natural disasters threatening the human population in the world, whose negative impacts span ecological, economic and social aspects. Accurate, timely and robust forecasts that can be used to minimize their damage are highly desirable. Factors including the ocean-atmosphere system, sea-surface temperature anomalies, solar-weather relationships, monsoon mechanism that affect the amount of rainfall eventually control drought attributes (Ponce *et al.*, 2000; Kim *et al.*, 2007; Chang and Oh, 2012). Qian and Zhou (2013) also investigated the forcing of PDO in modulating multidecadal variability of summer rainfall in East Asia and eventually affect the drought, as represented by PDSI. For a given region, if these attributes are determined, then the planning for drought

mitigation would be relatively simple. Unfortunately, however, the causes of drought are various, and even different for a separate region and each season. Moreover, it is not clearly understood how feedback of drought affects natural environments, which may in turn mitigate or intensify drought.

Since most elements that trigger droughts cannot be regulated, many countries rely on the drought monitoring system as the most effective system for allaying drought damage by early drought detection and issuing warnings (e.g., Boken *et al.*, 2005; Oh *et al.*, 2010). This has been carried out mainly by developing an indicator that allows for detection and evaluation of drought events. As a result, so many indices have been developed to quantify a drought to date. They include the Palmer drought severity index (PDSI; Palmer, 1965), rainfall anomaly index (RAI; van Rooy, 1965), deciles (Gibbs and Maher, 1967), crop moisture index (CMI; Palmer, 1968), standardized precipitation index (SPI; McKee *et al.*, 1993, 1995), the soil moisture drought index (SMDI; Hollinger *et al.*, 1993) and crop-specific drought index (CSDI; Meyer and Hubbard, 1995), and surface water supply index (SWSI; Shafer and Dezman, 1982), effective drought index (EDI; Byun and Wilhite, 1999). Each of these has its own strengths and weaknesses (e.g., Mishra and Singh, 2010; Dai, 2011).

To quantify the impact and the provision for abatement of drought it is necessary to understand its characteristics, such as, its possible duration, severity, and frequency of occurrence of droughts. Thus, study has been focused on temporal and spatial distributions of a drought index so far. That is, the time series of a drought index has been considered mostly in view of searching for a periodicity or for a correlation between other climate proxies and/or even among other types of drought indices (Rao *et al.*, 1992; Pandey and Ramasastri, 2001; Min *et al.*, 2003; Morid *et al.*, 2006, 2007; Byun *et al.*, 2008; Pandey *et al.*, 2008; Choi *et al.*, 2009; Kim and Byun, 2009; Kim *et al.*, 2009; Im *et al.*, 2012; Seo *et al.*, 2012; Yoo *et al.*, 2012; Sohn *et al.*, 2013a, b). Periodicity of droughts is examined typically using Fourier-based analysis method, such as, the Lomb-Scargle technique, the wavelet technique. Correlations are used to study with the spatial distribution of droughts in a wide range of a region. On the other hand, different analysis sometimes ends up with inconsistent conclusions not only

Corresponding Author: Heon-Young Chang, Department of Astronomy and Atmospheric Sciences, Kyungpook National University, Sangyeok 3-dong, Buk-gu, Daegu 702-701, Korea.
E-mail: hyc@knu.ac.kr

because different drought indices are deduced on the basis of different characteristics but also because the way of analyzing is insufficiently robust particularly when the data set is incomplete enough.

Instead, we here investigate the statistical properties of a drought index itself derived from a region for a long period of time. A hint from statistical analysis is likely to be helpful to constrain parameters in a drought model construction. For instance, Qian and Zhou (2013) investigated and tested the Gaussian distribution characteristics of North China PDSI for the period 1900-2010. In this contribution the drought climate of four cities in South Korea from 1913 to 2012 has been analyzed using a daily effective drought index (EDI). Even though we eventually aim to compare statistically our conclusions with ones drawn with other drought indices we decide to take here EDI as a pilot study for a couple of reasons. First, EDI is a daily based index which meets our requirements in counting for a given month the number of days whose EDI value is below the critical value of EDI that can be adjusted. Second, we could obtain the drought index for a time scale of 100 years since several observatories in South Korea where daily precipitation was recorded for longer than 100 years are available.

EDI is calculated as follows [see Byun and Wilhite (1999) for further details]. Firstly, Effective Precipitations (EPs) are used to compute deficiency or surplus of water resources for a particular date and place. EP here refers to the summed value of daily precipitation with a time-dependent reduction function. Once the daily EP is computed, a series of indices can be calculated to highlight different characteristics of a stations water resources. These are: Mean Effective Precipitation (MEP), Deviation of EP (DEP) and standardized value of DEP (EDI) of each day.

This paper begins with descriptions of time series of EDI data sets in Section 2. We present obtained results of statistical analysis of EDI in Section 3. Finally, we summarize and conclude in Section 4.

2. Time series of EDI

Byun and Wilhite (1999) developed EDI, which is a competent measure that considers daily water accumulation with a weighting function of time. Unlike many other drought indices, EDI utilizes daily precipitation data. In addition, EDI provides the available water resources index (AWRI) as an auxiliary index (Byun and Lee, 2002). Typically, EDI varies in the range from -2.0 to 2.0 . The drought range of EDI indicates extremely dry conditions at $EDI < -2.0$, severe drought at $-2.0 < EDI < -1.5$ and moderate drought at $-1.5 < EDI < -1.0$. Near normal conditions are indicated by $-1.0 < EDI < 1.0$. One would argue that the damage associated with droughts depends on the absolute value of water resources that are actually available at that particular instance rather than the deviation from the climatological mean value of water resources. However, one of advantages of EDI is that it can more accurately

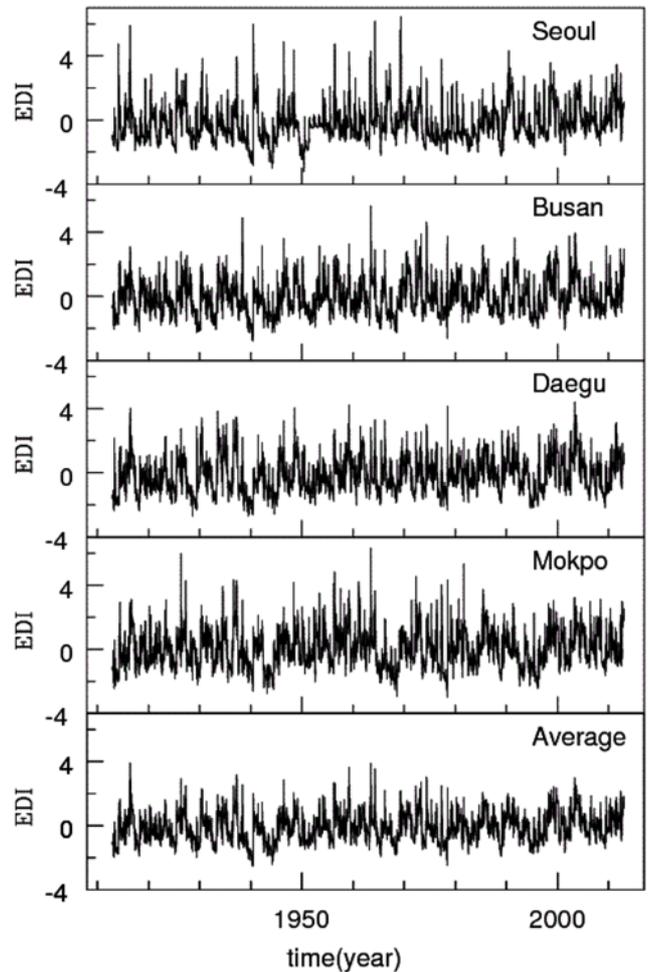


Fig. 1. Daily EDI as a function of time for Seoul, Busan, Daegu, Mokpo, and the average of EDIs from these four cities from top to bottom, during the period from 1913 to 2012, respectively.

determine the exact start and end of a drought period and the definition that the EDI is a function of ‘precipitation needed for a return to normal’ conditions (Byun and Wilhite, 1996).

We have used for the present analysis EDI of Seoul, Busan, Daegu and Mokpo in Korea during the period from 1913 to 2012. The data set has been taken from the Meteorological Disaster Research Laboratory website (<http://atmos.pknu.ac.kr/~intra2>), Department of Environmental Atmospheric Sciences, Pukyong National University. In Fig. 1, we show the daily EDI as a function of time for Seoul, Busan, Daegu, Mokpo, and the average of EDIs for these four cities from top to bottom, respectively. One may identify the year with relative ease when the severe drought occurred for a given city. When one analyzes the time series of EDI for a periodicity of droughts directly by the Fourier-based technique, however, outcomes should be interpreted with due care since the power spectrum may be dominated by signals due to periodic pulses of positive EDI values. In other words, the resulting power spectrum is a sum of signals due to pulses of positive and negative EDIs, since the time series like one shown in Fig. 1 commonly shows

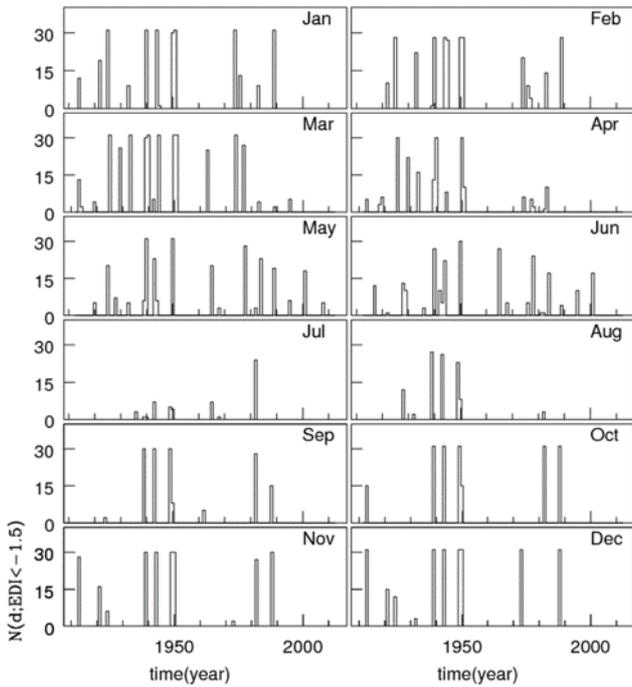


Fig. 2. Histograms of the number of days whose EDI < -1.5 for the month of the year indicated in the upper right corner of each panel, as a function of time. Plots result from Seoul.

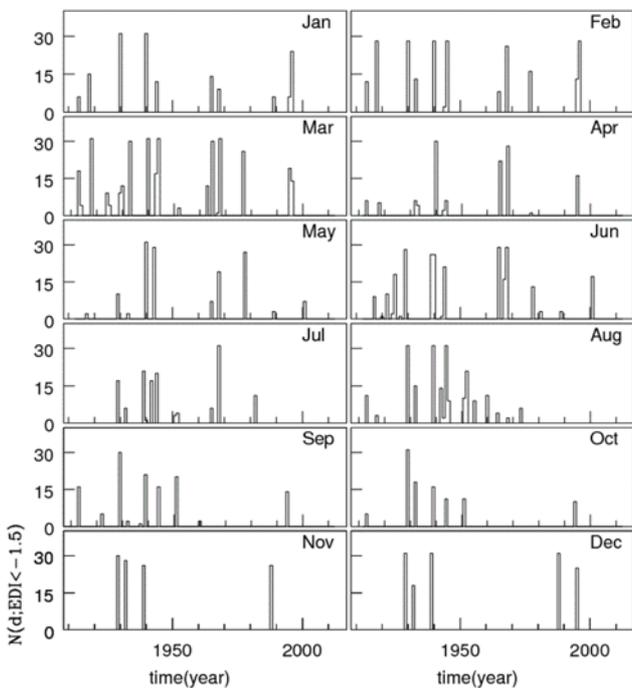


Fig. 3. Similar plots to Fig. 2, except resulting from Busan.

periodic behaviors of droughts (negative EDIs) and floods (positive EDIs) at the same time.

In Figs. 2 to 5, for a given city we show histograms of the number of days whose EDI is less than -1.5 , for the month of the year indicated in the upper right corner of each panel, as a

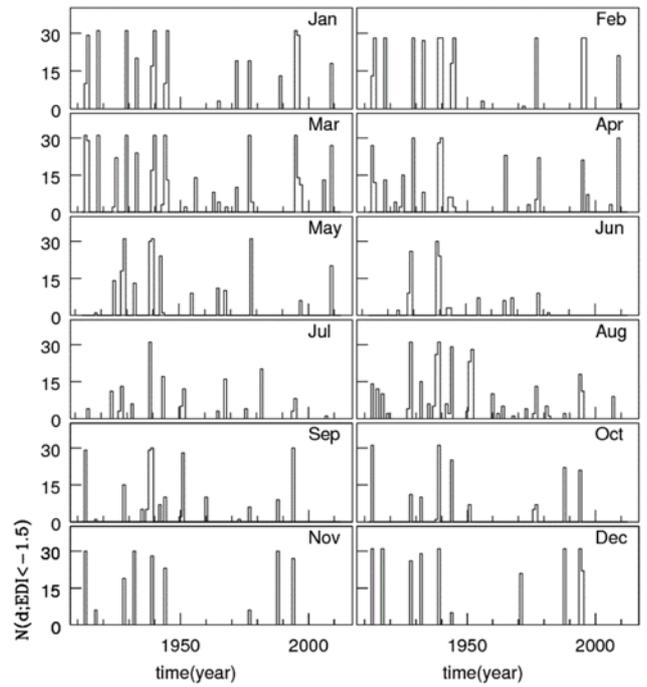


Fig. 4. Similar plots to Fig. 2, except resulting from Daegu.

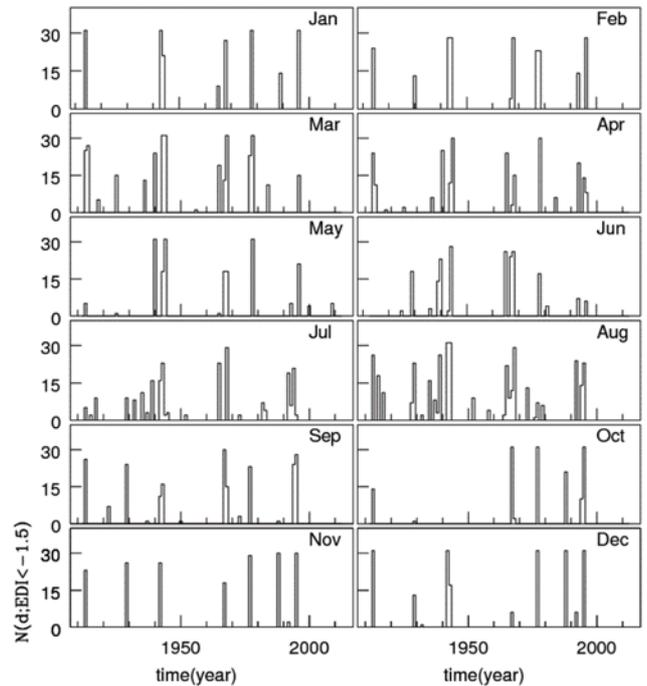


Fig. 5. Similar plots to Fig. 2, except resulting from Mokpo.

function of time. For instance, for the duration from 1913 to 2012 we have picked up every chunk of EDI data corresponding to January, for the uppermost left panel, and counted the number of days with EDI < -1.5 to plot against time of years. Figures 2 to 5 result from Seoul, Busan, Daegu, Mokpo, respectively. Note that the seasonal variation has been removed by counting the number of days whose EDI is less than

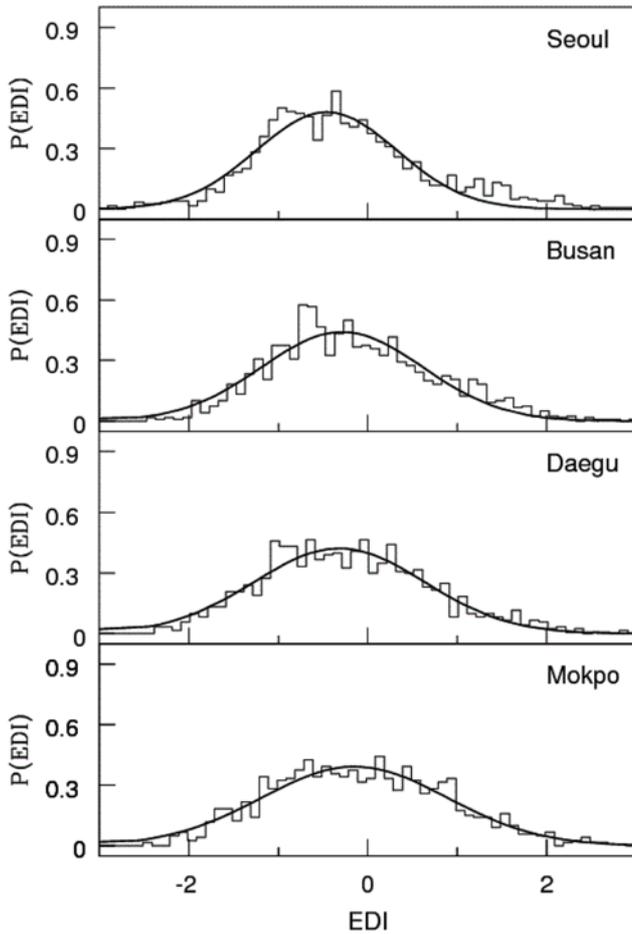


Fig. 6. Distributions $P(\text{EDI})$ of EDI as a function of EDI and their best fits using the Gaussian function, which is given by $A\exp[-(x-\bar{x})^2/2\sigma^2]$, where A , \bar{x} , and σ , represent the amplitude, the mean value, the full-width-at-half-maximum, respectively. The distributions result from EDIs for Seoul, Busan, Daegu, Mokpo during the period from 1913 to 2012, from top to bottom, respectively, as indicated in the upper right corner of each panel.

a critical EDI for each month of the year. Namely, each panel shows the time variation of the month over the years. In the early 1940s, there were severe droughts in four cities in common. In the mid 1990s, there were droughts in Busan, Daegu, Mokpo. On the other hand, in Seoul there were droughts in 1980s. We repeat the same analysis with $\text{EDI} < -2.0$, definitely confirming general findings we have described immediately above.

3. Statistical properties of EDI

In Fig. 6, we show distributions of EDI as a function of EDI and their best fits using the Gaussian function, which is given by $A\exp[-(x-\bar{x})^2/2\sigma^2]$, where A , \bar{x} , and σ , represent the amplitude, the mean value, the full-width-at-half-maximum, respectively. Having plotted EDIs for each city similarly to Fig. 1 we count the number of EDIs in each EDI bin with a bin-size of 0.1 for the whole range of the period, and normalize

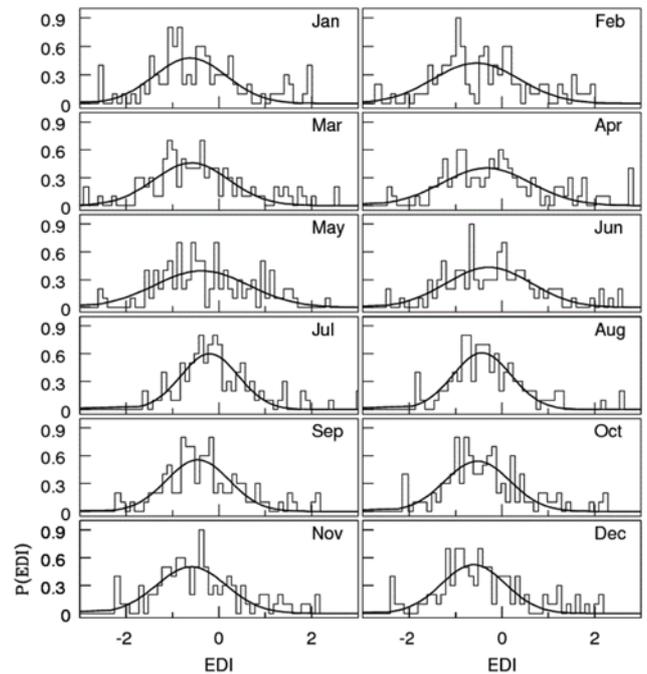


Fig. 7. Similar plots to Fig. 6, except resulting from the EDI data set of Seoul in which the month is indicated in the upper right corner of each panel. Unlike Fig. 6, we here show separate counts of the number of EDIs resulting from the specific month of the year during the period from 1913 to 2012. The month is indicated in the upper right corner of each panel.

such that the area under the distribution equals unity. We then fit a Gaussian function to the distribution by adjusting 3 parameters (amplitude, mean value, and full-width-at-half-maximum) at the same time using the method of least squares. The distributions result from EDIs for Seoul, Busan, Daegu, Mokpo during the period from 1913 to 2012, from top to bottom, as indicated in the upper right corner of each panel, respectively. We find the distribution of EDI follows the Gaussian function quite well, whose mean value is all negative implying that all the cities are essentially in dry condition on average. The numbers of days whose EDI is less than -1.5 are 76, 62, 92, 83 for Seoul, Busan, Daegu, Mokpo, respectively. We note that the total number of drought days defined as EDI of the day is less than a critical EDI is related both to the mean value and more importantly to the standard deviation. This is obviously because the total number of drought days is basically the area of the Gaussian function from the minus infinity to the critical EDI value. For instance, considering the critical EDI value is set to -1.5 , the area under the Gaussian function from -1.5 to the minus infinity depends on the standard deviation and the mean value as well, according to the definite integral of the Gaussian function. Mean values of EDI for Seoul, Busan, Daegu, Mokpo, are -0.45 , -0.28 , -0.31 , -0.14 , respectively. Standard deviations of EDI for Seoul, Busan, Daegu, and Mokpo are 1.11, 1.27, 1.34, and 1.46, respectively.

To figure out implications of the parameters obtained from the Gaussian fit, we repeat the counting process. Unlike results

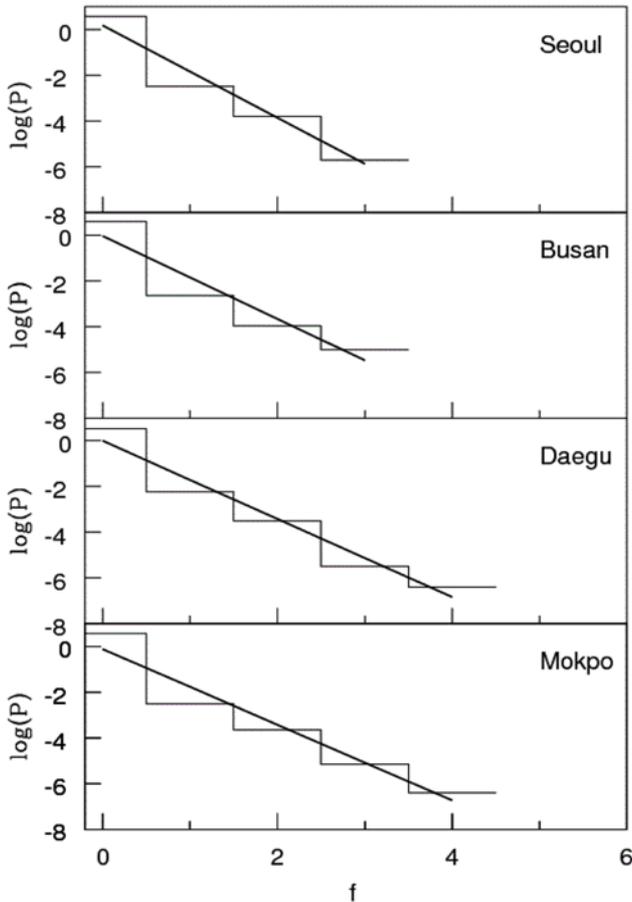


Fig. 8. Distributions, P , of the number of occasions, f , where the EDI values of three consecutive days are all less than -1.5 . The plot is in a log-linear scale. The distributions result from EDIs for Seoul, Busan, Daegu, Mokpo, from top to bottom, respectively, as indicated in the upper right corner of each panel. In each panel, the best fit of the exponential function is overlapped.

shown in Fig. 6, we here separately count by month the number of EDIs of the specific month of the year during the period from 1913 to 2012. In Fig. 7, as an example, we show similar plots resulting from the EDI data set of Seoul in which the month is indicated in the upper right corner of each panel. As shown in this particular example, in dry season the shape of the Gaussian function is characteristically broader than that in wet seasons. It should be pointed out that a skewed Gaussian seems unnecessary even in a dry season in that a symmetric Gaussian function fits to distributions both in rainy and in dry seasons. One might have expected there are more days of EDI < -1.5 so that the distribution is consequently skewed. It is shown here, however, that this is not the case. It is interesting enough to note that the standard deviation is apparently a more manifest factor than the mean value in dividing a data sample into two subsamples of wet and dry seasons. We have been further investigating how the parameters are related to records of drought, planning to report results in elsewhere (Park and Chang, in preparation).

In Fig. 8, we show distributions, P , of the number of

occasions, f , where the EDI values of three consecutive days are all less than -1.5 , which is a log-linear plot. The distributions result from EDIs for Seoul, Busan, Daegu, Mokpo, from top to bottom, as indicated in the upper right corner of each panel, respectively. We note that the distribution follows the exponential distribution well enough. In each panel, the best fit of the exponential function is overlapped. One may expect that when the critical EDI value becomes smaller or when the number of consecutive days increases the distribution is likely to be seen steeper. Repeating the whole process, we confirm that the slope of the best fit becomes steeper not only as the critical EDI value becomes more negative but also as the number of consecutive days increases. Hence, it can be suggested that the longevity of drought in time is to follow the exponential distribution.

4. Summary and conclusions

To understand duration, severity, and frequency of occurrence of droughts, study has been focused on temporal and spatial distributions of a drought index so far. We here investigate the statistical properties of a daily effective drought index (EDI) itself derived from precipitation data of Seoul, Busan, Daegu, Mokpo for the period of 100 years from 1913 to 2012. The data set has been taken from the Meteorological Disaster Research Laboratory, Department of Environmental Atmospheric Sciences, Pukyong National University.

Based on our approach in characterizing droughts, our main findings are as follows:

(1) The distribution of EDI as a function of EDI follows the Gaussian function in both dry and wet seasons. Mean values are all negative implying that all the cities we have analyzed are essentially in dry condition on average. The total number of drought days defined as EDIs of the day is less than a critical value of EDI is related both to the mean value and more importantly to the standard deviation. Moreover, in dry season the shape of the Gaussian function is characteristically broader than that in wet seasons.

(2) According to the distribution of the number of occasions where the EDI values of several consecutive days are all less than a threshold, the distribution follows the exponential distribution. It is also found that the slope of the best fit becomes steeper not only as the critical EDI value becomes more negative but also as the number of consecutive days increases.

We, therefore, conclude that distributions of EDI follow the Gaussian distribution. It is interesting to note that the standard deviation is apparently a more manifest factor than the mean value in dividing a data sample into two subsamples of wet and dry seasons. It requires further studies to relate the parameters to traits of drought, such as, severity. Drought is likely to occur when the distribution becomes broader and possibly when this distribution is shifted to the negative in general. The extent of drought both in time is to follow the exponential distribution.

Acknowledgments. This research was supported by Kyungpook National University Research Fund, 2012 (2013, 2014). HYC was supported by the National Research Foundation of Korea Grant funded by the Korean government (NRF-2011-0008123).

Edited by: Tianjun Zhou

REFERENCES

- Boken, V. K., A. P. Cracknell, and R. H. Heathcote, 2005: *Monitoring and predicting agricultural drought: A global study*. Oxford University Press, New York, 472 pp.
- Byun, H. R., and D. A. Whilite, 1999: Objective quantification of drought severity and duration. *J. Climate*, **12**, 2747-2756.
- _____, and D. K. Lee, 2002: Defining three rainy seasons and the hydrological summer monsoon in Korea using available water resources index. *J. Meteor. Soc. Japan*, **80**, 33-44.
- _____, S. J. Lee, S. Morid, K. S. Choi, S. M. Lee, and D. W. Kim, 2008: Study on the periodicities of droughts in Korea. *Asia-Pac. J. Atmos. Sci.*, **44**, 417-441.
- Chang, H. Y., and S. J. Oh, 2012: Does correction factor vary with solar cycle?. *J. Astron. Space Sci.*, **29**, 97-101.
- Choi, K. S., D. W. Kim, and H. R. Byun, 2009: Possible impact of spring sea ice anomaly in the North Pacific on the Korean summer drought. *Asia-Pac. J. Atmos. Sci.*, **45**, 331-346.
- Dai, A., 2011: Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, **2**, 45-65.
- Gibbs, W. J., and J. V. Maher, 1967: Rainfall deciles as drought indicators. Bureau of meteorology bull. 48, Commonwealth of Australia, Melbourne, Australia.
- Hollinger, S. E., S. A. Isard, and M. R. Welford, 1993: A new soil moisture drought index for predicting crop yields. *8th Conference on Applied Climatology*, Anaheim, CA, Amer. Meteor. Soc., 187-190.
- Im, E. S., J. B. Ahn, and D. W. Kim, 2012: An assessment of future dryness over Korea based on the ECHAM5-RegCM3 model chain under A1B emission scenario. *Asia-Pac. J. Atmos. Sci.*, **48**, 325-337.
- Kim, D. W., and H. R. Byun, 2009a: Future pattern of Asian drought under global warming scenario. *Theor. Appl. Climatol.*, **98**, 137-150.
- _____, _____, and K. S. Choi, 2009: Evaluation, modification, and application of the effective drought index to 200-year drought climatology of Seoul, Korea. *J. Hydrol.*, **378**, 1-12.
- Kim, M.-K., W. K. M. Lau, K.-M. Kim, and W.-S. Lee, 2007: A GCM study of effects of radiative forcing of sulfate aerosol on large scale circulation and rainfall in East Asia during boreal spring. *Geophys. Res. Lett.*, **34**, L24701.
- McKee, T. B., N. J. Doesken, and J. Kleist, 1993: The relationship of drought frequency and duration to time scales. *8th Conference on Applied Climatology*, Anaheim, CA, Amer. Meteor. Soc., 179-184.
- _____, _____, and _____, 1995: Drought monitoring with multiple time scales. *9th Conference on Applied Climatology*. Dallas, Texas, Amer. Meteor. Soc., 233-236.
- Meyer, S. J., and K. G. Hubbard, 1995: Extending the crop-specific drought index to soybean. *9th Conference on Applied Climatology*, Dallas, Texas, Amer. Meteor. Soc., 258-259.
- Min, S. K., W. T. KWON, E. H. Park, and Y. Choi, 2003: Spatial and temporal comparisons of droughts over Korea with East Asia. *Int. J. Climatol.*, **23**, 223-233.
- Mishra, A. K., and V. P. Singh, 2010: A review of drought concepts. *J. Hydrol.*, **391**, 202-216.
- Morid S., V. Smakhtin, and M. Moghaddasi, 2006: Comparison of seven meteorological indices for drought monitoring in Iran. *Int. J. Climatol.*, **26**, 971-985.
- _____, _____, and K. Bagherzadeh, 2007: Drought forecasting using artificial neural networks and time series of drought indices. *Int. J. Climatol.*, **27**, 2103-2111.
- Oh, S. B., D. W. Kim, K. S. Choi, and H. R. Byun, 2010: Introduction of East Asian drought monitoring system. *SOLA*, **6A**, 009-012.
- Palmer, W. C., 1965: Meteorologic drought. US department of commerce, weather bureau, Research Paper, **45**, 1-58.
- _____, 1968: Keeping track of crop moisture conditions, nationwide: The new crop moisture index. *Weatherwise*, **21**, 156-161.
- Pandey R. P., and K. S. Ramasastri, 2001: Relationship between the common climatic parameters and average drought frequency. *Hydrol. Process.*, **15**, 1019-1032.
- _____, B. B. Dash, S. K. Mishra, and R. Singh, 2008: Study of indices for drought characterization in KBK districts in Orissa (India). *Hydrol. Process.*, **22**, 1895-1907.
- Ponce, V. M., R. P. Pandey, and S. Ercan, 2000: Characterization of drought across climatic spectrum. *J. Hydrol. Eng.*, ASCE, **5**, 222-224.
- Qian, C., and T. Zhou, 2013: Multidecadal variability of North China aridity and its relationship to PDO during 1900-2010. *J. Climate*, doi: 10.1175/JCLI-D-13-00235.1.
- Rao, A. R., G. D. Jeong, and F. J. Chang, 1992: Estimation of periodicities in hydrologic data. *Stochastic Hydrol. Hydraul.*, **6**, 270-288.
- Shafer, B. A., and L. E. Dezman, 1982: Development of a Surface Water Supply Index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. *Western SnowConf.*, Reno, NV, Colorado State University, 164-175.
- Seo, L., T. W. Kim, and H. H. Kwon, 2012: Investigation of trend variations in annual maximum rainfalls in South Korea. *KSCE J. Civ. Eng.*, **16**, 215-221.
- Sohn, S. J., C. Y. Tam, and J. B. Ahn, 2013a: Development of a multimodel-based seasonal prediction system for extreme droughts and floods: a case study for South Korea. *Int. J. Climatol.*, **33**, 793-805.
- _____, _____, and _____, 2013b: Six month-lead downscaling prediction of winter to spring drought in South Korea based on a multimodel ensemble. *Geophys. Res. Lett.*, **40**, 579-583.
- Van Rooy, M. P., 1965: A rainfall anomaly index independent of time and space. *Notos*, **14**, 43-48.
- Yoo, J., H. H. Kwon, T. W. Kim, and J. H. Ahn, 2012: Drought frequency analysis using cluster analysis and bivariate probability distribution. *J. Hydrol.*, **420-421**, 102-111.