Drought over Seoul and Its Association with Solar Cycles

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We have investigated drought periodicities occurred in Seoul to find out any indication of relationship between drought in Korea and solar activities. It is motivated, in view of solar-terrestrial connection, to search for an example of extreme weather condition controlled by solar activity. The periodicity of drought in Seoul has been re-examined using the wavelet transform technique as the consensus is not achieved yet. The reason we have chosen Seoul is because daily precipitation was recorded for longer than 200 years, which meets our requirement that analyses of drought frequency demand long-term historical data to ensure reliable estimates. We have examined three types of time series of the Effective Drought Index (EDI). We have directly analyzed EDI time series in the first place. And we have constructed and analyzed time series of histogram in which the number of days whose EDI is less than -1.5 for a given month of the year is given as a function of time, and one in which the number of occasions where EDI values of three consecutive days are all less than -1.5 is given as a function of time. All the time series data sets we analyzed are periodic. Apart from the annual cycle due to seasonal variations, periodicities shorter than the 11 year sunspot cycle, ~ 3, ~ 4, ~ 6 years, have been confirmed. Periodicities to which thses short periodicities (shorter than Hale period) may be corresponding are not yet known. Longer periodicities possibly related to Gleissberg cycles, ~ 55, ~ 120 years, can be also seen. However, periodicity comparable to the 11 year solar cycle seems absent in both EDI and the constructed data sets.

Keywords: drought, EDI, solar cycles, data analysis

1. INTRODUCTION

Timely and accurate forecasts that can be used to minimize their damage are highly desirable since droughts are among the greatest natural disasters threatening the human population in the world. Unfortunately, however, the causes of drought are various, and even different for a separate region and each season, and, moreover, most elements that trigger droughts cannot be regulated. This is partly why 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). Factors including relationships between solar activity and terrestrial weather that affect the amount of rainfall eventually controlling drought attributes have been under careful scrutiny to understand its characteristics, namely its possible duration, intensity/severity, and frequency (Ponce et al. 2000, Kim et al. 2009, Chang & Oh 2012).

In the meantime there is growing interest in roles that the Sun plays on terrestrial weather and climate, not to mention space weather (Svensmark & Friis-Christensen 1997, Tinsley 2000, Scafetta & West 2006, Cho & Chang 2008, Kniveton et al. 2008, Cho et al. 2012). Changes in the temperature and dynamics in the troposphere are suggested to correlate with the Earth's magnetic/electric changes corresponding to solar activities (Burns et al. 2007, 2008). The study of responses of atmospheric ionization and the global electric circuit to varying GCRs demonstrates that the atmospheric transparency is associated with GCR flux which itself is modulated by the solar magnetic field (Roldugin & Tinsley 2004). The response of daily sea-level pressure (SLP) over...
Korean Peninsula to the high-speed solar wind stream (HSS) is examined, resulting in 0.81 with day lag in the correlation coefficient between the average profiles of superposed SLP and HSS (Cho et al. 2012).

The solar activity cycles excite periodical and pseudo periodical variations of all Earth systems, such as, climate, water cycles, rainfalls, streamflows, groundwater, and so on. This rhythm has been associated with possible forcing by the Hale solar magnetic cycle and/or the 18.6-year lunar nodal cycle (Hodell et al. 2001, Hwang et al. 2005, Byun et al. 2008, Penalba & Vargas 2004, Leal-Silva & Velasco Herrera 2012, Yoo et al. 2012). For instance, Cook et al. (1997) made an assessment of these possible solar/lunar forcings on drought area index (DAI), finding a reasonably strong statistical association between the bidecadal drought area rhythm in the Western United States and years of Hale solar cycle minima and 18.6-year lunar tidal maxima. Analysis of the historical time series of rainfall data in Italy has revealed significant 11-year, 22-year and 44-year variabilities that are possibly linked to coherent fluctuations in the high-speed solar wind precipitation into the atmosphere (Mazzarella & Palumbo 1992). Periods corresponding to the 11 year sunspot cycle, the Hale cycle and others have been detected in various hydrologic data (Rao et al. 1992). The Southern Oscillation Index (SOI) is also shown to track the pairing of sunspot cycles in ~88 year periods (Landscheidt 2000, Baker & Palumbo 1992). Periods corresponding to the 11 year sunspot cycle, the Hale cycle and others have been detected in various hydrologic data (Rao et al. 1992). The Southern Oscillation Index (SOI) is also shown to track the pairing of sunspot cycles in ~88 year periods (Landscheidt 2000, Baker 2008, Bettolli et al. 2010).

As mentioned above, drought occurs due to various causes. In some places, the solar forcing may thus play a role on one hand. In other places, on other hand, it can be overshadowed by other reasons, such as meteorological causes, even if the Sun might have a playing role indeed, so that the association of the solar forcing with drought is negligible in a drought modeling. One may be interested in finding such a relation with data collected in Korea when especially tailored model for Korean drought is under development. Min et al. (2003) have found that the frequency of occurrence of droughts in Korea has significant time intervals of 2-3 and 5-8 years and has been increasing since the 1980s using the Standardized Precipitation Index (SPI) as a drought index. Wang et al. (2007) have also analyzed monthly precipitation data from the Seoul observatory and showed that spectral peaks exist in 4-year cycles. Recently, Byun et al. (2008) have claimed that drought periodicities correlated with the solar cycles can be found in records of precipitation of Seoul and in other available data including records of ritual praying for rain, drought damage, and years of deficient precipitation for the duration of 536 years. In their analysis, drought intensity is quantified by using the Effective Drought Index (EDI), which is an intensive measure that considers daily water accumulation with a weighting function for time passage (Byun & Whilhite 1999). EDI is one of widely used drought indices, including the Palmer drought severity index (PDSI; Palmer 1965), rainfall anomaly index (RAI; van Rooy 1965), deciles (Gibbs & Maher 1967), crop moisture index (CMI; Palmer 1968), standardized precipitation index (SPI; McKee et al. 1993, 1995), and crop-specific drought index (CSDI; Meyer & Hubbard 1995), and surface water supply index (SWSI; Shafer & Dezman 1982). Compared to other drought indices, the EDI has several advantages (see, e.g., Mishra & Singh 2010).

In this contribution the periodicity of drought in Seoul, where daily precipitation was recorded from 1778 to 2012, has been re-examined using the wavelet transform technique (e.g., Chang 2006). By doing so, the solar influences on local variations of drought can be investigated by means of available time series of observed meteorological data. This analyzing technique is used in many fields of physics and engineering, such as, acoustics, geophysics, helioseismology, image processing, and so on. It is a very powerful tool to obtain information on the temporal behavior of an oscillatory signal. This paper is organized as follows. We begin with brief descriptions of data in Section 2. We present and discuss results in Section 3. Finally, we summarize and conclude in Section 4.

2. DATA

We have used for the present analysis EDI of Seoul in Korea during the period from 1778 to 2012. The data set has been taken from the Meteorological Disaster Research Laboratory website, Department of Environmental Atmospheric Sciences, Pukyong National University. Time series of EDIs for other stations distributed in South Korea, North Korea, Japan, and China can be also obtained as ASCII text files. Computer codes for EDI are provided so that one may easily appreciate how EDI is defined and computed. 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. In Fig. 1, we show the daily EDI as a function of time for Seoul. One may identify the year with relative ease when the severe drought occurred.

3. RESULTS AND DISCUSSION

In Fig. 2, we show result from the wavelet transform
analysis of the data shown in Fig. 1. The horizontal axis represents time in day counting from the beginning of the data for 235 years, and the vertical axis the cyclic frequency in $\frac{1}{\text{day}}$. The power is shown in gray scale. The power is scaled by the mean value of the noise. Several high power peaks appear at $-0.00274$, $-0.001$, $-0.00075$, $-0.0002$ $\frac{1}{\text{day}}$, whose periods correspond to $\sim 1$, $\sim 2.7$, $\sim 3.7$, $\sim 5.5$, $\sim 15$ years, respectively. The most dominant peak is the one of frequency $\sim 0.00274$ $\frac{1}{\text{day}}$. It is due to the fact that drought has a seasonal variation. That is, in Korea basically we have rainy summer seasons and dry spring and winter seasons, which leads an annual modulation. We have found some marginal peaks corresponding to periods of $\sim 70-100$ years. But considering that the total data length is 235 years peaks should be regarded as statistically insignificant. We, therefore, conclude that periodicities associated with the solar cycles cannot be found in time series of EDI data. Another point to note is that most power is concentrated in 19th century and that in modern times there seems no severe drought occurred. Unlike the Fourier analysis, the wavelet transform analysis does also show where the modes of the signal exist in time. This is a strong point of the wavelet transform analysis over the traditional Fourier-based analysis. This finding can be understood in the sense the average value of EDI is more negative in 19th century implying severity of drought, as seen in Fig. 1.

In Fig. 3, we show result from the wavelet transform analysis of time series of histogram in which the number of days whose EDI is less than $-1.5$ for a given month of the year is given as a function of time. The horizontal axis represents time in month counting from the beginning of the data for 235 years, and the vertical axis the cyclic frequency in $\frac{1}{\text{month}}$. The power is shown in gray scale. The power is again scaled by the mean value of the noise. High peaks can be seen at $-0.083$, $-0.028$, $-0.022$, $-0.014$ $\frac{1}{\text{month}}$, whose periods correspond to $\sim 1$, $\sim 2.9$, $\sim 3.8$, $\sim 6$ years, respectively. The most dominant peak is obviously the one of frequency $-0.083$ $\frac{1}{\text{month}}$. In Fig. 4, we show similar plot to Fig. 3, except the vertical scale is different. Here, we see peaks at $-0.0015$, $-0.0007$ $\frac{1}{\text{month}}$, whose periods correspond to $\sim 55$, $\sim 120$ years, respectively. Even though a peak at $-0.007$ $\frac{1}{\text{month}}$ corresponding to the 11 year solar cycle does not appear in the power spectrum, peaks possibly related to Gleissberg cycles can be found. We have repeated the
same analysis with the critical EDI setting to -2.0 instead of -1.5. We find peaks at the same frequencies. Yet, any peaks relating 11 year solar cycle cannot be found. We point out that, despite apparent similarity, searching for a periodicity in a power spectrum resulting from the histogram as in Figs. 3 and 4 is rather a proper way than from time series of EDI itself as in Fig. 2. Since the time series like one shown in Fig. 1 commonly shows periodic behaviors of droughts (negative EDIs) and floods (positive EDIs) at the same time, the resulting power spectrum is a sum of signals due to pulses of positive and negative EDIs. Hence, power spectrum as shown in Fig. 2 should be interpreted with due care.

In Fig. 5, we show result from the wavelet transform analysis of time series in which the number of occasions where EDI values of three consecutive days are all less than -1.5 is given as a function of time. By this, we meant to count severe or prolonged droughts. Here we show the power spectrum of occurrence of severe droughts in a sense. The horizontal axis represents time in month, and the vertical axis the cyclic frequency in $\frac{1}{\text{month}}$. The power is shown in gray scale normalized by the mean value of the noise. High peaks can be seen at ~0.083, ~0.039, ~0.028, ~0.022, ~0.013, ~0.01 $\frac{1}{\text{month}}$, whose periods correspond to ~1, ~2.1, ~2.9, ~3.8, ~6.4, ~8.3 years, respectively. In Fig. 6, we show similar plot to Fig. 5, except the vertical scale is different. Here, we see peaks at ~0.0015, ~0.0007 $\frac{1}{\text{month}}$, whose periods correspond to ~55, ~120 years, respectively. Even though a peak at ~0.007 $\frac{1}{\text{month}}$ corresponding to the 11 year solar cycle does not appear in the power spectrum, peaks possibly related to Gleissberg cycles can be found. We have repeated the same analysis with the critical EDI setting to -2.0 instead of -1.5. We also repeated a case of five consecutive day long drought with critical EDI of -1.5 and -2.0. Generally speaking, same conclusions are drawn so that our conclusion is robust.

4. SUMMARY AND CONCLUSION

The main purpose of study on periodicities of droughts is to provide a scientific tool to predict their occurrences in the future. Another scientific motivation in view of solar-terrestrial connection is to search for an example of extreme weather condition controlled by solar activity. We have investigated drought periodicities occurred in Seoul to find out any indication of a relationship between drought in Korea and solar activities. The periodicity of drought in Seoul, where daily precipitation was recorded from 1778 to 2012, has been re-examined using the wavelet transform technique as the consensus is not achieved yet. The reason we have chosen Seoul is because daily precipitation was recorded for longer than 200 years, which meets our requirement that analyses of drought frequency demand long-term historical data to ensure reliable estimates.

Supposed the site is a random choice from homogeneous stations in Korea, we have investigated the solar influences
on local variations of drought in Korea using time series data sets constructed with EDI data. We have examined three types of time series of EDI. We have directly analyzed EDI time series in the first place. And we have constructed and analyzed time series of histogram in which the number of days whose EDI is less than -1.5 for a given month of the year is given as a function of time, and one in which the number of occasions where EDI values of three consecutive days are all less than -1.5 is given as a function of time. We have repeatedly generated and tested similar time series data with different criteria too. All the time series data sets we analyzed are periodic. Apart from the annual cycle, periodicities shorter than the 11 year sunspot cycle reported have been confirmed. Longer periodicities possibly related to Gleissberg cycles can be also seen. However, periodicity comparable to the 11 year sunspot cycle seems absent in both EDI and the constructed data sets.

ACKNOWLEDGMENTS

HYC was supported by the National Research Foundation of Korea Grant funded by the Korean government (NRF-2011-0008123).

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