Journal of Hydrology 534 (2016) 237–250

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Teleconnections of the ENSO and South Korean precipitation patterns

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ARTICLE INFO

Article history:
Received 27 October 2015
Accepted 7 January 2016
Available online 12 January 2016
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Bruno Merz, Associate Editor

Keywords:
El Niño
La Niña
El Niño/Southern Oscillation
Precipitation

SUMMARY

The climatic relationship of the ENSO phenomena (El Niño/La Niña) and monthly precipitation patterns over South Korea is examined based on the composite and harmonic analysis. Three core regions, namely the Upper Region (UR), the Middle Region (MR), and the Lower Region (LR), were identified with a high level of the spatial coherence and temporal consistency rate, which represent the geographical extent and magnitude of the response of the ENSO forcing to the precipitation patterns. During the El Niño events, the February (+) to May (+), November (0) to April (+), and November (0) to May (+) wet period for UR, MR, and LR respectively, are the signal seasons having a high level of coherence and consistency. The spatial coherence rates of each region are 0.94, 0.98, and 0.98, and the temporal consistency rates are 0.80, 0.90, and 0.80 respectively. On the other hand, in case of the La Niña events, the October (0) to January (+), November (0) to May (+) dry period for UR and MR respectively, are the signal seasons showing a strong and consistent teleconnection. The spatial coherence rates of each region are 0.98, 0.96 and the temporal consistency rates are both 0.78. According to the comparative analyses for both extreme episodes, in three core regions, the El Niño/La Niña–precipitation relationships show the opposite sign, positive and negative precipitation anomalies respectively. Based on the results of annual cycle analysis, Mann–Whitney *U* hypothesis test and cross-correlation analysis, the wet anomalies during the warm event years, which prevail over the whole region, are more remarkable and significant than the dry departures during the cold event years. In conclusion, the climatic teleconnection between the extreme phase of SO and mid-latitude precipitation is identified over South Korea.

1. Introduction

El Niño and La Niña are opposite climate phenomena characterized by the unusual wide-ranging warming and cooling of the sea surface temperature ranging from the central to eastern tropical Pacific Ocean, due to the weakening and strengthening of the trade winds (easterlies) which blow predominantly through the eastern to the western Pacific by air pressure differences. These two types of fluctuations of the sea surface temperature are interactive with the Southern Oscillation (SO) defined as an atmospheric pressure circulation over the eastern–western equatorial Pacific with a periodic seesaw pattern. The interaction of the above oceanic fluctuation and atmospheric oscillation defines the El Niño/Southern Oscillation (ENSO), well known as a naturally occurring phenomenon involving fluctuating ocean temperatures over the central–eastern tropical Pacific Ocean, coupled with changes in the atmosphere (WMO, 2014).

Since the first approaches by Walker (1923) and Walker and Bliss (1932) to the impact of the extreme phase of SO on the variation of Indian monsoon rainfall, in the recent decades many global scale studies associated with ENSO showed remarkable climatic link between precipitation patterns and both warm and cold phases of Southern Oscillation (SO) in various areas of the world. Berlage (1966) showed the statistically significant correlations between climate indices of the SO and precipitation patterns in some regions of the globe, and Rasmusson and Carpenter (1983) revealed evidence of significant linkage between the evolution of the ENSO and anomalies in precipitation and surface temperature over the tropical Pacific. Moreover, more recent studies by Bradley et al. (1987), Ropelewski and Halpert (1987, 1989), and Kiladis and Diaz (1989), revealed noticeable ENSO–precipitation relationships with the identification of the seasons and regions having a consistent response of the warm and cold phases of SO to the precipitation pattern over the several regions of the globe. Also, Westra et al. (2013) investigated the presence of trends in annual maximum daily precipitation at global scale using Mann–Kendal test and generalized extreme value analysis for a significant association with globally averaged near-surface atmospheric temperature.

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http://dx.doi.org/10.1016/j.jhydrol.2016.01.011
0022-1694/

Much of the regional scale work relating the extreme phase of SO to hydrometeorological parameters over low and middle latitude by Douglas and Englehart (1981), Shukla and Paolino (1983), Rasmusson and Wallace (1983), Ropelewski and Halpert (1986), Redmond and Koch (1991), Kahya and Dracup (1994) and Price et al. (1998), found plausible evidence of strong and coherent links between ENSO and precipitation patterns. In detail, for mid-latitude regions, the importance of the ENSO–precipitation relationships is emphasized in several studies. Douglas and Englehart (1981), as well as, Ropelewski and Halpert (1986) reveal that ENSO is associated with enhancement of the winter precipitation in the southeastern United States, and the climatic relationship between low and high phases of SO and North American precipitation have been investigated by Ropelewski and Halpert (1986) and Kiladis and Diaz (1989). Dai (2013) examined the influence of the inter-decadal Pacific Oscillation (IPO) on United States precipitation using observational and reanalysis data and model simulations. Karabörk and Kahya (2003) detected coherent regions in Turkey where precipitation is associated with El Nino and La Nina events. Cai et al. (2011) diagnosed the impacts of ENSO on Australian rainfall from the perspective of tropical and extratropical teleconnections triggered by tropical SST variation and Power et al. (2006) examined the relationship between ENSO and all-Australian rainfall with a coupled general circulation model. Jin et al. (2005) identified statistically significant correlations between the extreme phases of SO and Korea–Japan precipitation patterns based on the cross-correlation analysis using the categorized SOI classified by five groups according to their magnitudes. Chandimala and Zubair (2007) investigated the predictability of seasonal rainfall for the Kelani river basin in Sri Lanka associated with ENSO and SST using correlation analysis and principal component analysis.

In South Korea, several recent studies exist concerning precipitation patterns associated with the ENSO events (El Niño/La Niña). Lee (1998) applied harmonic analysis to investigate the relationship between both extreme phases of SO and temperature/precipitation over South Korea. Cha et al. (1999) investigated the relationship between El Niño/La Niña events and the climate in Korea using synoptic data and ECMWF (European Centre for Medium-range Weather Forecasts) grid data, and showed that El Niño forcing has a tendency to modulate the precipitation over Korea by enhancing or suppressing with respect to seasons. Shin (2002) showed significant correlation between the warm/cold episodes and the floods/droughts in South Korea using statistically robust cross-correlation analysis.

As seen from the above, the majority of previous global/regional scale studies have focused on mostly the Pacific Rim countries. These studies revealed the significant teleconnection between the ENSO forcing and hydrometeorological variations in the lower to mid latitudes. However, the impact of El Nino and La Nina events on the mid to high latitudes is not clear. The global scale study by Ropelewski and Halpert (1987, 1989) showed significant ENSO–precipitation relationship in some regions over the globe, with some potential for the signal over the East Asia. According to a visual inspection of station locations in the above study, the existence of the ENSO signals is not clearly identified in South Korea due to the limitation of data coverage. This indicates the need for a diagnostic investigation, supported by adequate and sufficient dataset, of the impact of ENSO forcing over South Korea.

The main objectives of this investigation are to: (1) identify coherent, consistent, and significant response of the warm extreme phase of SO (El Niño) to the precipitation patterns over South Korea, using a composite and harmonic analysis based on the improved description of the magnitude, phase, and geographical extent of the ENSO-related precipitation response; (2) investigate the climatic link between the precipitation patterns and the cold extreme phase of SO (La Niña) using the same composite and harmonic analysis as the above El Niño case; (3) examine the comparison between El Niño and La Niña–precipitation relationships with the viewpoint of intensity and trend of the significant responses, by comparative analyses such as an annual cycle analysis, a Mann–Whitney *U* hypothesis test, and a cross-correlation analysis.

2. Data set and methodology

2.1. Data set

The time series of monthly precipitation records applied in this analysis *are* based on 76 stations distributed all over South Korea. The source of these dataset is Korea Meteorological Administration (KMA) which is a governmental organization under the Ministry of Environment (MOE) monitoring and operating the overall Korean meteorology. The time series extend from 1904 to 2014 and cover more than about 20 episodes of El Niño and La Niña. Not only the meteorological stations with missing data for more than a season were excluded, but also the stations with less than 42 years of data or spanning less than 9 ENSO events were ruled out from the analysis. Finally, by taking the temporal persistency and spatial distribution into consideration, a subset of 60 gauging stations are selected in this study (Fig. 1).

In order to detect a consistent influence of ENSO episodes on precipitation pattern over South Korea, a wide set of ENSO events is selected by a comprehensive range of criteria based on the definition and classification by Quinn et al. (1978), Rasmusson and Carpenter (1983), Ropelewski and Halpert (1987, 1989), Kiladis and Diaz (1989), and Trenberth (1997). The overall ENSO years applied in this analysis are displayed in Table 1.

As a method of representing large-scale climate fluctuation over the Pacific Ocean, a climatic index known as the Southern Oscillation Index (SOI) is employed. The time series of SOI are calculated using the difference of the standardized anomalies of the sea level atmospheric pressures between the Tahiti and Darwin, Australia. The time series of SOI calculated by the NOAA Climate Prediction Center is applied in the present study.

2.2. Methodology

The methodological approach for understanding and predicting teleconnection patterns consists of empirical orthogonal teleconnection (EOT), cross correlation analysis, mean *t*-test and harmonic analysis (e.g., Klingaman et al., 2013; King et al., 2014; McBride and Nicholls, 1983; Jin et al., 2005; Kahya and Dracup, 1994; Ropelewski and Halpert, 1986, 1987). In this present study, to provide a logical extension of the global scale study associated with the ENSO–precipitation teleconnection, an empirical methodological approach designed by Ropelewski and Halpert (1986, 1987) is applied with some changes and additions.

Fig. 2 shows the schematic description for the overall methodology used in this study, based on Ropelewski and Halpert (1986, 1987). The detailed procedures of the methodology comprise primarily three stages, namely, data processing, analytical method application, and comparative analysis stage. The first stage is intended for transforming the original raw data into an appropriate data format such as SPI, non-exceedance probability series, categorized SOI, and modular coefficients. The second stage is to detect candidate regions and confirm core regions based on composite and harmonic analysis. And the last stage is focused on the comparative interpretation on El Niño and La Niña–precipitation relationships using annual cycle analysis, Mann–Whitney *U* test, and cross-correlation analysis.