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RELATIONSHIPS BETWEEN ENSO AND DROUGHTS IN KOREA AND THE CONTINENTAL U.S.

Dong-Ryul Lee[1] and Jose D. Salas[2]

[1]Korea Institute of Construction Technology, Kyonggi-Do, Korea
[2] Department of Civil Engineering, Colorado State University, Colorado, USA

Abstract: The teleconnections between El Niño/Southern Oscillation (ENSO) and droughts in Korea and in the continental United States (U.S.) are investigated using cross correlation analysis. For this purpose, monthly ENSO data and Palmer Drought Severity Index (PDSI) for Korea and for seven states in the U.S. are used. This study shows that there are significant statistical associations between ENSO indices and PDSI for Korea; however, the associations are very weak. It is found that dry conditions in Korea are positively correlated with El Niño, while wet conditions with La Niña. SOI, SST in the Niño 4 and Ship track 6 regions among ENSO indices are more strongly correlated with the PDSI than the other ENSO indices when using the original standardized data, but the SST Niño 3, SST Niño 4, and Darwin SSP exhibit a better correlation with PDSI when using filtered data to be removed autocorrelation components of the original standardized data. The response time lag for maximum correlation between ENSO indices and PDSI appears to be affected by filtering the data. This is especially true for Korea than for the states analyzed in U.S. In addition, it is found that the PDSI in the continental U.S. is more strongly correlated with ENSO than in Korea. Furthermore, in analyzing the El Niño and La Niña aggregate composite data, it is found that the dry anomalies in Korea occur from the year following El Niño to about two years after while the wet anomalies occur from La Niña year for a period of about two years.

Key words: ENSO, teleconnections, Palmer Drought Severity Index, drought, cross correlation

1. INTRODUCTION

There have been many studies on teleconnections between ENSO and hydrologic parameters, for many regions worldwide such as near the equatorial Pacific, North and South America, Southeast Asia, India, and Africa. But the relationships between ENSO and the Asian Pacific Northeast, especially Korea opposite to the U.S. Pacific Northwest, have not been well documented. Halpert and Ropelewski (1992) indicated that the U.S. Pacific Northwest and Japan are warmer and colder in the year after El Niño and La Niña episodes, respectively. The Pacific Northwest also was identified as the region of significant response with respect to the evolution of ENSO episode in parameters such as temperature, precipitation, and streamflow (Ropelewski and Halpert, 1986; Kiladis and Diaz, 1989, Redmond and Koch, 1991; Kahya

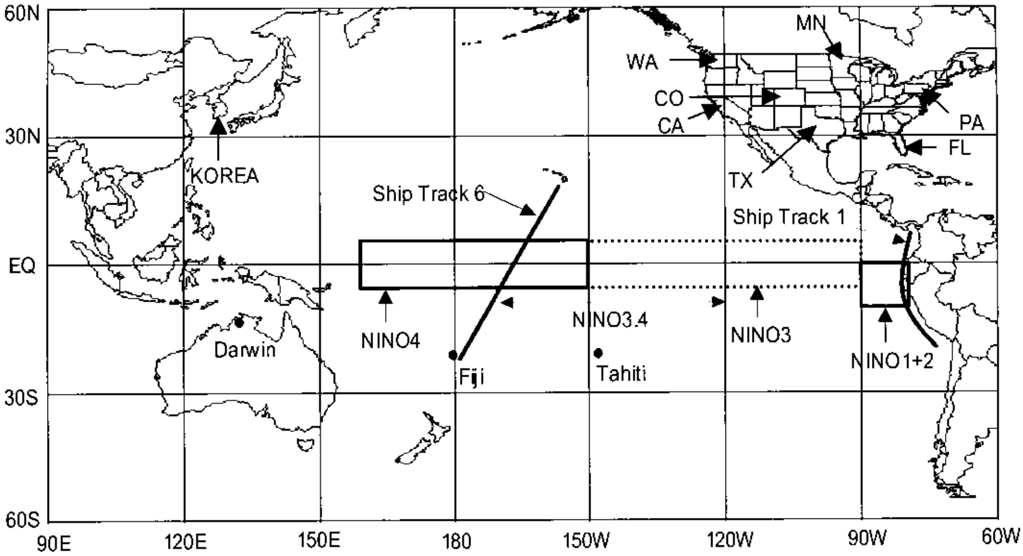


Fig. 1. Study Regions

and Dracup, 1993; Piechota and Dracup, 1996). Kiladis and Diaz (1989) also showed that eastern China and southern Japan have wet conditions after El Niño episodes. Although there are some investigations of the teleconnections of ENSO and the Asian Pacific Northeast, to the knowledge of the authors, no direct study has been made linking droughts with ENSO.

The objective of this paper is to identify the relationships between ENSO and droughts in the Asian Pacific northeast especially in Korea. An additional objective is to examine the teleconnections of droughts in the continental U.S. and Korea. For this purpose, the Palmer Drought Severity Index (PDSI) evaluated for several states in the USA and in Korea have been correlated with ENSO indices. The results of the analysis may provide some valuable information about drought episodes that may occur simultaneously in two different and distant areas of the earth. In addition, composite percentile analysis introduced by Ropelewski and Halpert (1986) is performed to reconfirm the results of the correlation analysis between ENSO and PDSI for Korea.

2. DATA DESCRIPTION

The study regions consist of Korea and seven states in U.S., namely Washington (WA), California (CA), Colorado (CO), Texas (TX), Florida (FL), Minnesota (MN), and Pennsylvania (PA). Fig. 1 shows the geographic location of the study regions.

2.1 PDSI Data

The monthly time series of PDSI for WA, CA, CO, TX, FL, MN, and PA for the period 1951-1996 were obtained from the U.S. National Climate Data Center (NCDC). Each state is divided into several climatic divisions, respectively, and NCDC provides PDSI for each division. The time series representative of each state was obtained by averaging the PDSI values of the divisions.

To obtain PDSI for Korea, the procedure developed by Palmer (1965) was utilized based on

Fig. 2. The locations of the meteorological gauging stations for calculating PDSI in Korea

monthly precipitation (*mm*) and temperature (℃). Fig. 2 shows the study area in Korea and the location of the gauging stations. PDSI is a measure of meteorological drought. It measures the cumulative difference between normal precipitation and Climatically Appropriate For Existing Conditions (CAFEC) precipitation (Palmer, 1965). Finally, the derived equation for calculating the PDSI for Korea is

$$X_i = 0.926 X_{i-1} + 0.01336 Z_i \tag{1}$$

where X_i = PDSI, Z_i = moisture anomaly index, and i = time in months. The PDSI series for the nine stations shown in Fig. 2 were calculated from Eq. (1), and then the mean PDSIs for the nine stations were assumed to represent the PDSI for Korea.

2.2 ENSO indices

Nine ENSO raw indicators were obtained from the U.S. Climate Prediction Center (CPC). They are Tahiti and Darwin sea surface pressure (SSP), sea surface temperature (SST) for Niño 1+2 (0-10°S, 90°W-80°W), Niño 3 (5°N-5°S, 150°W-90°W), Niño 4 (5°N-5°S, 160°E-150°W), Niño 3.4 (5°N-5°S, 170°W-120°W), Ship Track 1 (ST 1), and Ship Track 6 (ST 6). ST 1 parallels the Central and South American coasts and ST 6 crosses the equator near Canton Island (Rasmusson and Carpenter, 1982). Fig. 1 shows the location of the referred sites.

Southern Oscillation Index (SOI) is derived by standardizing the monthly time series of the difference between SSP at Tahiti and at Darwin. Fig. 3 shows the time series of SOI, the monthly standardized time series of SST in the Niño 4 and PDSI for Korea and for WA. The referred figure gives some indication that PDSI for WA and Korea are related to both SOI and SST.

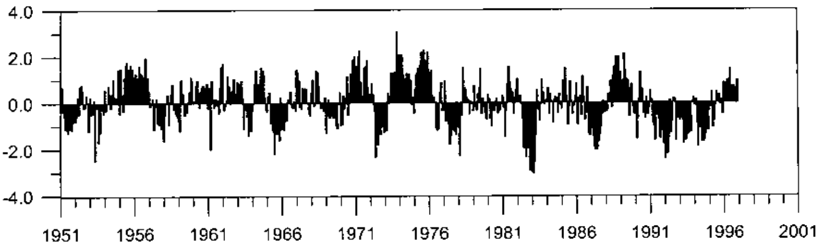
3. DATA ANALYSIS AND RESULTS

Cross-correlation analysis was used to investigate the linear relationship between PDSI and the ENSO indices. The analysis was made under the following conditions: 1) Standardized data of ENSO and PDSI, 2) Filtered data of ENSO and PDSI. The standardized data were obtained by

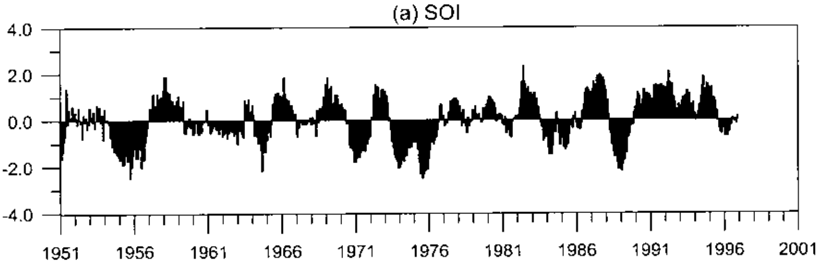
$$z_{\nu,\tau} = \frac{(x_{\nu,\tau} - \bar{x}_\tau)}{s_\tau} \tag{2}$$

where $x_{\nu,\tau}$ = original monthly value such as PDSI, $\bar{x}_\tau$ = the monthly means, $z_{\nu,\tau}$ = standardized value, and s_τ is the monthly standard deviation.

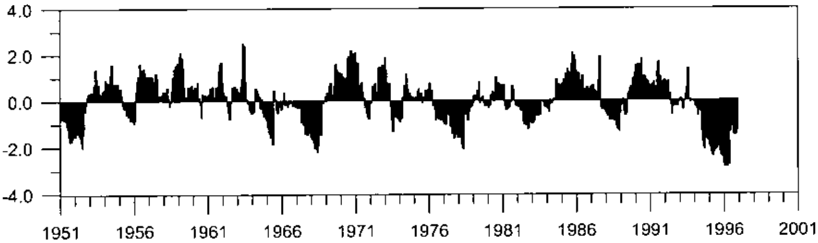
The search for teleconnections usually involves the calculation of the sample cross correlation function for the pairs of time series. But the existence of autocorrelation can lead to apparent leading or lagging relationships when the relationships are not actually present. Further,



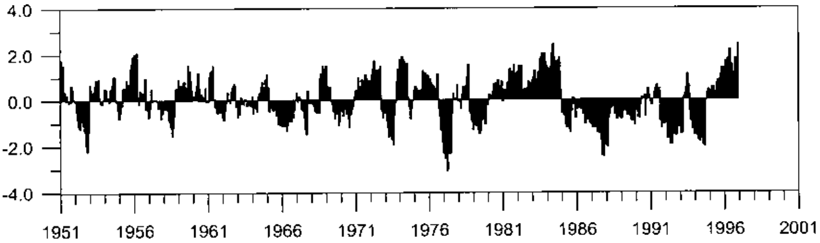
(a) SOI



(b) SST(Niño 4 region)



(c) PDSI for Korea



(d) PDSI for WA

Fig. 3. SOI, monthly standardized time series of SST for Niño 4 region, and PDSI for Korea and WA.

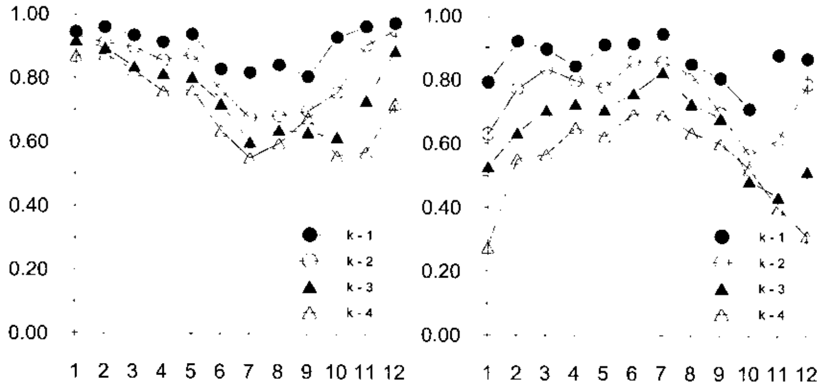
the effect of autocorrelation of the individual time series is to 'smear out' any contemporaneous cross correlation that might be present (Katz, 1988). In such cases, filtering may be necessarily before estimating the cross correlation coefficients. In fact, PDSI and ENSO indices have strong autocorrelation as shown in Fig. 4 and Fig. 5.

The standardized data were filtered by using the lag-1 periodic autoregressive PAR(1) model

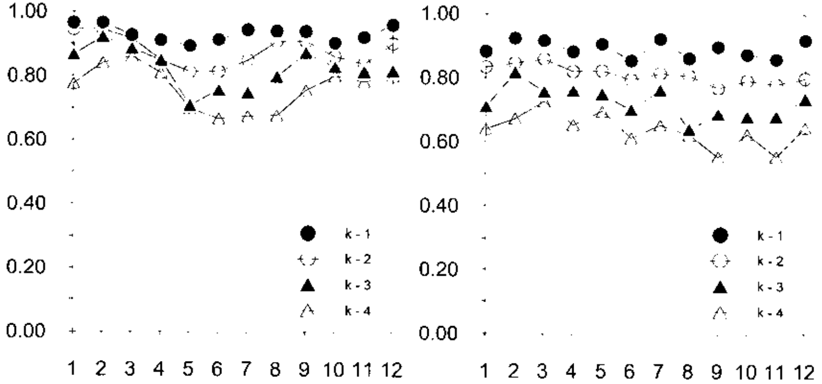
$$z_{\nu,\tau} = \phi_{1,\tau} z_{\nu,\tau-1} + \varepsilon_{\nu,\tau} \tag{3}$$

where $\varepsilon_{\nu,\tau}$ is the filtered series, $\phi_{1,\tau}$ is the lag-1 month-to-month correlation coefficient, and $z_{\nu,\tau}$ is the standardized variable from (2).

Considering the periodic series $x^{(i)}_{\nu,\tau}$ and

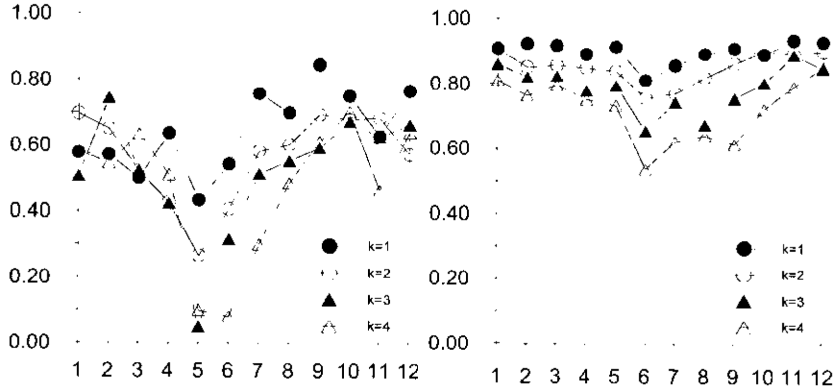


(a) Korea (b) WA



(c) CO (d) FL

Fig. 4. Lag-k month-to-month correlation coefficients for PDSI for Korea and WA, CO, and FL states



(a) SO (b) Niño 4 region

Fig. 5. Lag-k month-to-month correlation coefficients for SO and Niño 4 SST

$x^{(j)}_{\nu,\tau}$ for site i and j, the lag-k month-to-month cross-correlation coefficient $r^{ij}_{k,\tau}$ is given by

$$r^{ij}_{k,\tau} = \frac{1}{N} \frac{\sum_{\nu=1}^{N} (x^{(i)}_{\nu,\tau} - \bar{x}^{(i)}_{\tau})(x^{(j)}_{\nu,\tau-k} - \bar{x}^{(j)}_{\tau-k})}{s^{(i)}_{\tau} s^{(j)}_{\tau-k}} \tag{4}$$

Table 1. Cross correlations between the standardized ENSO indices and PDSI based on Eq. (4)

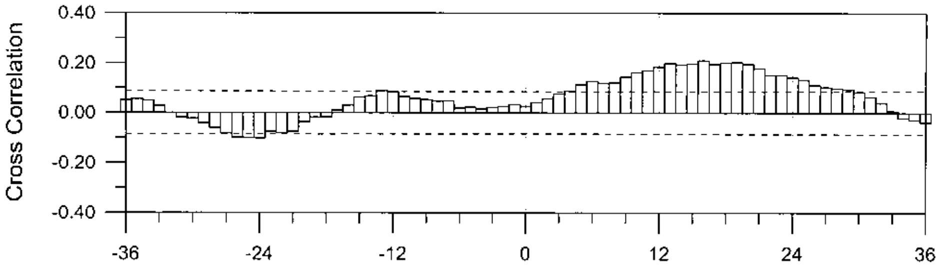
ENSO Indices	Korea		WA		CA		CO	
	lag-k	max. corr.	Lag-k	max. corr.	lag-k	max. corr.	lag-k	max. corr.
Tahiti SSP	19	0.175	4	0.224	9	-0.205	9	-0.176
Darwin SSP	13	-0.196	5	-0.237	5	0.186	3	0.270
SOI	16	0.210	4	0.274	8	-0.209	5	-0.262
Niño 1+2 SST	14	-0.053	7	-0.217	2	0.329	6	0.347
Niño 3 SST	14	-0.137	7	-0.278	3	0.293	6	0.299
Niño 4 SST	18	-0.223	3	-0.340	6	0.184	6	0.338
Niño 3.4 SST	18	-0.181	4	-0.323	3	0.222	6	0.285
Ship track1 SST	14	-0.048	7	-0.195	2	0.311	6	0.356
Ship track6 SST	16	-0.235	3	-0.346	6	0.175	4	0.307
ENSO Indices	TX		FL		MN		PA	
	lag-k	max. corr.	Lag-k	max. corr.	lag-k	max. corr.	lag-k	max. corr.
Tahiti SSP	3	-0.162	1	-0.207	9	-0.121	-2	0.083
Darwin SSP	5	0.205	7	0.175	-3	0.128	-2	-0.133
SOI	3	-0.223	6	-0.306	-4	-0.140	-2	0.130
Niño 1+2 SST	4	0.249	0	0.196	-2	0.164	-16	0.125
Niño 3 SST	3	0.282	2	0.271	-3	0.190	-1	-0.094
Niño 4 SST	3	0.371	4	0.440	-5	0.148	4	-0.145
Niño 3.4 SST	2	0.325	2	0.379	-3	0.185	-1	-0.143
Ship track1 SST	2	0.270	0	0.193	-2	0.154	-16	0.137
Ship track6 SST	2	0.373	3	0.466	-7	0.163	4	-0.165

* 95% confidence level is ± 0.083, 99% confidence level is ± 0.11

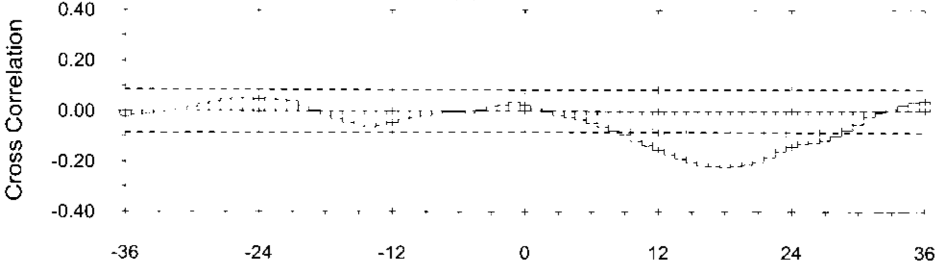
where $\bar{x}_\tau^{(i)}$ and $\bar{x}_{\tau-k}^{(j)}$ are the periodic means at time interval τ and τ-k, respectively, and $s_\tau^{(i)}$ and $s_{\tau-k}^{(j)}$ are the periodic standard deviations at time interval τ and τ-k, respectively.

The maximum cross correlation coefficient (CCC) among multiple coefficients computed by Eq. (4) and the lag-k (month) for the maximum CCC are given in Table 1. Most of the ENSO indices lead PDSI for almost all sites, but PDSI for MN and PA lead ENSO indices. The results show that the Tahiti SSP and SOI give results in the same direction for all sites considered. In addition, the results for Tahiti SSP and SOI are generally opposite to those for the other indices. For example, considering the results for Korea, while the correlation between PDSI and SOI is positive (+0.21), the correlations between PDSI and SSTs are negative. In general, the three indices with the highest correlation throughout the study area are Niño 4, Niño 3.4, and Ship Track 6. Furthermore, the correlations in Table 1 suggest that Korea and the state of Washington respond similarly to the ENSO condition although the effect of ENSO on the state of Washington is more significant than that on Korea. Moreover, except for the states of Minnesota and Pennsylvania, the correlations with ENSO indices are more significant for North America than for Korea.

Fig. 6 and 7 show some of the correlations for Korea and for the state of Washington, respectively based on the original standardized data. A notable feature shown in the figures is the different maximum response (correlation) time that is about 16-18 months for Korea, while about

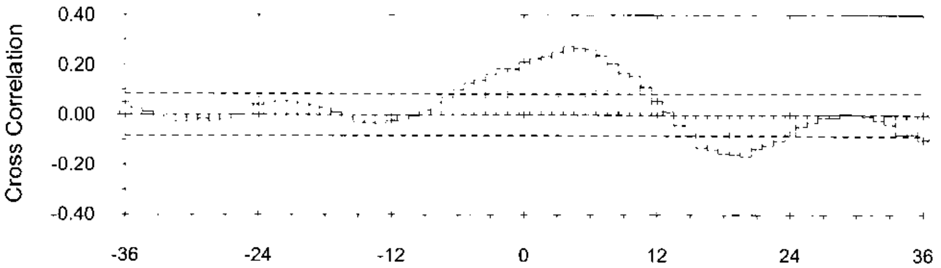


(a) SOI - PDSI

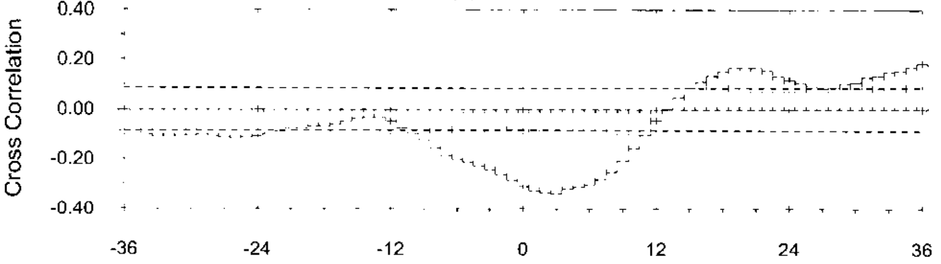


(b) SST(Niño 4 region) - PDSI

Fig. 6. Lag correlations between SOI and Niño 4 SST and PDSI for Korea



(a) SOI - PDSI



(b) SST(Niño 4 region) - PDSI

Fig. 7. Lag correlations between SOI and Niño 4 SST and PDSI for WA

3-6 months for Washington. However, Tables 1 and 2 also show the different response time for maximum correlations that may be obtained when correlations are calculated based on the original or filtered data. This is especially noticeable in the case of Korea.

The CCC computed by Eq. (4) after filtering using Eq. (3) is given in Table 2. As Katz (1988) indicated, maximum CCC for the filtered data becomes smaller than those for standardized

Table 2. Cross correlations between filtered ENSO indices and PDSI. Filtering is done based on Eq. (3)

ENSO Indices	Korea		WA		CA		CO	
	lag-k	max. corr.	lag-k	max. corr.	lag-k	max. corr.	lag-k	max. corr.
Tahiti SSP	16	0.082	-3	0.095	9	-0.116	9	-0.127
Darwin SSP	6	-0.131	7	-0.103	-3	0.105	3	0.140
SOI	16	0.098	4	0.111	1	-0.078	2	-0.113
Niño 1+2 SST	7	-0.089	7	-0.120	3	0.124	7	0.130
Niño 3 SST	-10	-0.155	7	-0.136	3	0.127	0	0.105
Niño 4 SST	-1	0.148	3	-0.133	6	0.088	0	0.102
Niño 3.4 SST	-10	-0.100	7	-0.104	2	0.091	6	0.107
Ship track1 SST	-1	0.084	8	-0.106	3	0.110	7	0.115
Ship track6 SST	-1	0.118	3	-0.116	8	0.093	0	0.117
ENSO Indices	TX		FL		MN		PA	
	lag-k	max. corr.	lag-k	max. corr.	lag-k	max. corr.	lag-k	max. corr.
Tahiti SLP	-3	-0.116	1	-0.120	-4	-0.081	-2	0.073
Darwin SLP	10	-0.100	-2	0.100	-13	0.083	-2	-0.096
SOI	10	0.121	1	-0.124	-12	-0.093	-2	0.118
Niño 1+2 SST	-2	0.092	0	0.114	-2	0.086	-7	0.084
Niño 3 SST	1	0.094	0	0.123	-3	0.111	5	-0.072
Niño 4 SST	5	0.101	6	0.100	4	0.090	23	0.110
Niño 3.4 SST	1	0.107	6	0.135	-3	0.103	5	-0.087
Ship track1 SST	-2	0.094	0	0.116	-2	0.092	-8	-0.087
Ship track6 SST	1	0.107	6	0.118	4	0.111	4	-0.077

* 95% confidence level is ± 0.083, 99% confidence level is ± 0.11

data (Table 1), and the lag times for maximum CCC are changed between few ENSO indices and PDSI. These results confirm that the existence of high autocorrelation can lead to apparent leading or lagging relationships when none may be actually presented. However, the relationships between most of filtered ENSO indices and PDSIs for Korea and for the continental U.S. still show statistical significance.

The results of the cross correlation between PDSI for Korea and PDSI for various states in the continental U.S. are given in Table 3. The relationships between WA, CA, MN, and PN and Korea are negative, while those between CO and FL and Korea are positive.

To analyze ENSO aggregate composites for PDSI in Korea, 10 El Niño years (1953, 1957, 1965, 1969, 1972, 1976, 1982, 1986, 1991, and 1994) and 6 La Niña years (1955, 1964, 1970, 1973, 1975, and 1988) between 1951 and 1996 were selected. Piechota and Dracup (1996) also used the ENSO aggregate composite and PDSI in the continental U.S. The standardized PDSI data were expressed as percentiles for each month at each station in Fig. 2. The El Niño 36 months aggregate composite for the nine stations in Fig. 2 show that dry anomalies occur from the year following El Niño to two years later April (+2) (Fig 8a). The driest season is from Jan (+2) to April (+2). On the other hand, La Niña 36 months aggregate composite for the same stations show anomalies opposite than those in the El Niño composite, but wet anomalies occur from La Niña year (Fig. 8b).

Piechota and Dracup (1996) showed the PDSI composite for WA. When a comparison is made

Table 3. Correlations between PDSI for Korea and PDSI of States in U.S. Note that the PDSI for states leads the PDSI for Korea

PDSI for States in the continental U. S. A.	PDSI for Korea			
	Standardized data		Filtered data	
	lag-k	max. corr.	lag-k	max. corr.
Washington(WA)	-6	-0.187	-2	-0.134
California(CO)	-7	-0.361	-7	-0.095
Minnesota(MN)	-9	-0.166	-3	-0.073
Pennsylvania(PN)	-9	-0.138	0	-0.088
Florida(FL)	-1	-0.202	-1	-0.128
Colorado(CO)	-11	0.094	-12	0.096
Texas(TX)	-12	0.206	-13	0.105

* 95% significant level is ± 0.083, 99% significant level is ± 0.11

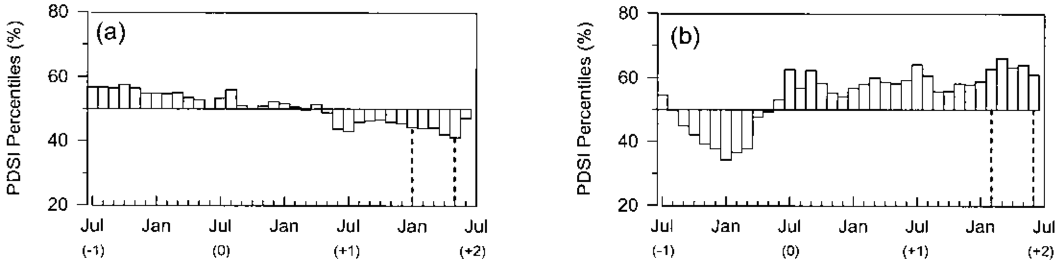


Fig. 8. (a) El Niño and (b) La Niña 36 months aggregate composites for PDSI in Korea

between El Niño composites for PDSI in Korea and in WA, the lag in the response of the driest season related El Niño for WA is faster than for Korea.

4. CONCLUSIONS

The objective of this paper is to identify the relationships between ENSO and droughts in the Asian Pacific northeast especially in Korea. An additional objective is to examine the teleconnections of droughts in the continental U.S. and Korea. For this purpose, the Palmer Drought Severity Index (PDSI) evaluated for several states in the USA and in Korea have been correlated with ENSO indices. In addition, composite percentile analysis introduced by Ropelewski and Halpert (1986) is performed to reconfirm the results of the correlation analysis between ENSO and PDSI for Korea.

This study shows that there are significant statistical associations between ENSO indices and PDSI for Korea; however, these relationships alone are not strong enough for in accurately predicting droughts.

It is found that dry conditions in Korea are positively correlated with El Niño, while wet conditions with La Niña. Among the ENSO indices, SOI, SST in the Niño 4 and Ship Track 6 regions exhibit a better correlation with the PDSI than the other ENSO indices when using the original standardized data. However, the ENSO indices that more strongly correlated with PDSI are SST Niño 3, SST Niño 4, and Darwin SSP, when using filtered data to be removed autocorrelation components of the original standardized data. The response time lag for maximum correlation between ENSO indices and PDSI appears to be affected by filtering the data. This is especially true for Korea than for the states analyzed in U.S. In addition, it is found that the PDSI in the continental U.S. is more strongly correlated with ENSO than in Korea.

Furthermore, in analyzing El Niño and La Niña aggregate composite data, it is found that the dry anomalies in Korea occur from the year following El Niño to about two years after while the wet anomalies occur from La Niña year for a period of about two years.

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Dong-Ryul Lee, Water Resources and Environmental Research Division, Korea Institute of Construction Technology, Ilsan-Gu, Koyang-Shi, Kyonggi, 411-712, Korea
(E-mail : dryi@kict.re.kr)

Jose D. Salas, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado 80523, USA

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