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ENSO index teleconnection with seasonal precipitation in a temperate ecosystem of northern Mexico

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RESUMEN

La Oscilación del Sur El Niño (ENSO, por sus siglas en inglés) es el principal fenómeno de circulación de gran escala que ocasiona variabilidad climática en el norte de México. El desafío actual consiste en entender sus consecuencias para los procesos climáticos y ecológicos de los ecosistemas. En este contexto, se comparó el grado de asociación de tres diferentes índices de ENSO con la precipitación local (*P*) en el norte de México, y se utilizaron series dendrocronológicas (cronologías de anillos de crecimiento [TRI, por su siglas en inglés]) de *Pinus cooperi* para valorar su impacto en el crecimiento forestal. Los resultados mostraron un asociación importante entre ENSO, la precipitación del invierno anterior y el TRI ($r > 0.5$, $p = 0.05$), lo cual indica que hay una relación directa entre las fases cálidas de ENSO y el crecimiento de los árboles. El índice multivariado de ENSO explicó ligeramente mejor que otros índices la conexión entre *P* y el crecimiento radial. Estos resultados pueden apoyar futuras investigaciones sobre los efectos de ENSO en el clima local y los ecosistemas forestales.

ABSTRACT

El Niño Southern Oscillation (ENSO) is the most important large-scale circulatory phenomenon that causes climatic variability in northern Mexico. The current challenge is to understand its consequences for both local climate and ecological processes of ecosystems. Within this context, we compared the degree of association of three different ENSO indices with local seasonal precipitation (*P*) in northern Mexico, and used dendrochronological series (tree-ring chronologies [TRI]) of *Pinus cooperi* to assess the impact of forest growth. The results showed a strong association between ENSO, previous winter precipitation and TRI ($r > 0.5$, $p = 0.05$), indicating a positive relationship between warm ENSO phases and subsequent tree growth. The multivariate ENSO index was slightly better at explaining the connection between *P* and radial growth than other indices. These results could be used to support further research on the effects of ENSO on local climate and forest ecosystems.

Keywords: Winter precipitation, *Pinus cooperi*, tree rings, Niño 3.4, MEI, MEI.ext.

1. Introduction

The teleconnections of El Niño Southern Oscillation (ENSO) with global climate have been widely documented (e.g., Peralta, 2008; Birk *et al*., 2010). The different phases of ENSO are strongly associated with the occurrence of extreme climatic phenomena, including tropical cyclone incidence (e.g., Gutzler *et al*., 2013). This is a matter of major concern because such climatic variations add to the stresses imposed on ecosystems by anthropogenically induced global warming (e.g., Williams *et al*., 2013). This becomes vitally important in geographic areas that are highly sensitive to ENSO, but where its effects allow the prediction of seasonal-scale climate behavior with some degree of confidence (Wolter *et al*., 1999; Gutzler *et al*., 2013).

The north of Mexico represents one such area. It is a region that experiences recurrent drought and for which a teleconnection with the ENSO phenomenon has been reported (Seager *et al*., 2009). ENSO is known to alter several ecological processes (Griffin *et al.*, 2011). In northern Mexico, ENSO correlates well with instrumental winter precipitation (Cleveland *et al*., 2003) and it strongly influences climatic conditions (Villanueva *et al*., 2007). In this regard, the Niño 3.4 index corrrelates well with precipitation anomalies (Meko *et al*., 2013). ENSO also influences the intensity of the dry and wet spells that have been recorded in the upper Nazas River watershed during the past century (Cerano *et al*., 2011). However, not all processes are simply related to ENSO. For example, its effects on fire occurrence have changed over time and thus, ENSO phases are not considered consistent indicators of fire occurrence or behavior (Yocom *et al*., 2010).

The relationships of ENSO with the aforementioned phenomena have been assessed using conventional ENSO indices, such as the Southern Oscillation Index and the Niño 3.4 index. However, the use of these indices is complicated as a result of their variations and climate responses through annual cycles, which reduce their reliability (Wolter and Timlin, 1998). An alternative index is the multivariate ENSO index (MEI), which is the first principal component of six observed fields (Wolter and Timlin, 1993). However, a major limitation of the MEI is the reduced time span of available records, i.e., from 1950 to the present. To overcome this, an extended MEI (MEI.ext) was proposed by Wolter and Timlin (2011), who generated index values from 1871 to 1950. They claim that the MEI is more reliable and robust relative to conventional indices; however, there has been no comparative evaluation of its potential in explaining local climate.

As ENSO remains the most relevant large-scale circulatory phenomenon that induces climatic variability, the important issue is to understand its effects on local climate and thus, on the ecological processes of ecosystems. Therefore, we performed a comparison of the degree of association of three different ENSO indices with local seasonal precipitation, and related them to the radial growth of *Pinus cooperi.* This coniferous tree, which has high ecological and economic value, is representative of northern Mexico and its growth has previously been shown to relate to large-scale circulatory patterns (Cruz *et al*., 2008; Pompa-García and Jurado-Ybarra, 2013).

2. Methods

2.1 Study area

The study area, bounded by the coordinates 24º 13'-23º 44' N, 105º 22'-105º 34' W, is located in the temperate ecosystem of the Sierra Madre Occidental in Mexico, where *P. cooperi* is abundant (Fig. 1). Pompa-García and Jurado-Ybarra (2013) reported a teleconnection response of precipitation in this area to ENSO. Tree-ring samples were collected from five sampling locations within the study area for growth evaluation. Using standard dendrochronological techniques, local tree-ring chronologies (TRI) were generated (Pompa-García *et al*., 2013a), which were taken as representatives of the common climate signal for the site.

2.2 Data and statistical analysis

To evaluate how ENSO affects local climate, we considered the instrumental records from two meteorological stations located nearest to the source of the dendrochronology data. These weather stations, called El Salto and Otinapa, belong to the Comisión Nacional del Agua (National Water Commission) (CNA, 2012). We organized and analyzed the historical records from 1950 to 2005 for the following climate variables: previous summer precipitation (*PSP*), previous winter precipitation, (*PWP*), and current summer precipitation (*CSP*). These variables were calculated by adding the precipitation in millimeters recorded over different time spans, for which the current year corresponds to the year of tree-ring formation: *PSP*, from June to September in the previous year; *PWP*, from the previous October to the current February; and *CSP*, from June to September in the current year (which is the growing season).

We related these variables to values of the following ENSO indices: MEI, MEI.ext, and Niño 3.4 for 1950-2005, considering lags from the previous-year January to the current-year December. The MEI is the first seasonally varying principal component of

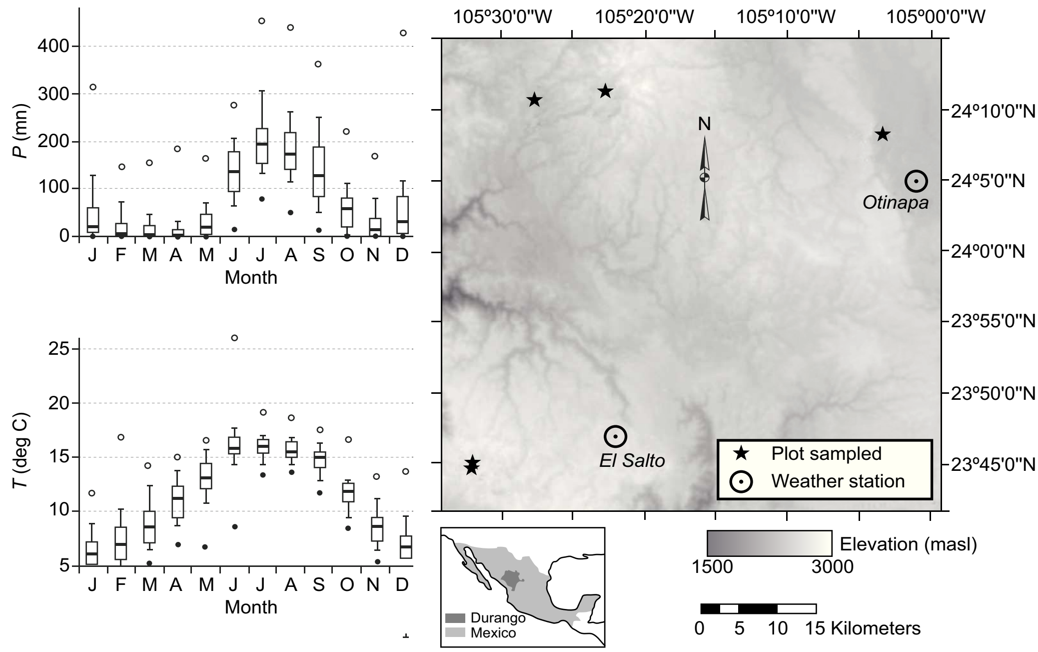

Fig. 1. Site locations and regional climatogram. The map shows the study area where cores of *Pinus cooperi* were sampled (right). The climatograph illustrates the distribution of monthly precipitation (*P*) and temperature (*T*) for the period 1950-2010 (left).

six atmosphere-ocean variable fields in the Tropical Pacific basin (Wolter and Timlin, 1993): sea level pressure, zonal and meridional components of surface wind, sea surface temperature, surface air temperature, and total cloud fraction. We retrieved its values from http://www.esrl.noaa.gov/psd/ENSO/MEI/table.html. As an alternative to Niño 3.4, the MEI.ext, which is based on sea level pressure and sea surface temperature, is potentially more reliable (Wolter and Timlin, 2011). Information regarding this index is available at http://www.esrl.noaa.gov/psd/ENSO/MEI.ext/table.ext.html. The Niño 3.4 index is a measure of sea surface temperature anomaly in the east-central equatorial Pacific, and it is available at http://iridl.ldeo.columbia.edu/SOURCES/.Indices/.nino/.EXTENDED/.

To establish the relationship between precipitation variables, regional tree chronologies, and the selected ENSO indices, we used the DendroClim2002 software (Biondi and Waikul, 2004), which computes the statistical significance of the correlation coefficients by calculating 95% quantile limits based on a 1000 bootstrap resample of the data. Furthermore, we also evaluated the association of seasonal precipitation (*P)* and TRI to ENSO variability within this region, using scatter plots.

3. Results

There is a strong association between the ENSO index, local seasonal precipitation, and the behavior of the tree-ring series (Fig. 2). This yielded Pearson correlation coefficients from −0.25 to 0.53 (with significances at a 0.05 level). Two of the three considered ENSO indices revealed strong coherence with *CSP* and tree growth; the exception was Niño 3.4, which exhibited no coherence at all.

The values of ENSO indices from the previous-year May to the current-year June showed the highest correlation with *PWP*. ENSO values from the previous May to the current April also had a consistent and positive relation with *PSP* in Niño 3.4. It was found that such a relation extends up to the current May, although in a weakened form. ENSO values from the previous May to the current January showed the highest correlation with *CSP*. However, the Niño 3.4 index showed a negative association in the current-year April and May. A similar pattern was found for *TRI*, which had the closest association with ENSO in the winter before the growing season.

The bootstrapped procedure conducted on *TRI* and monthly ENSO indices presented positive associations with radial growth over the study area.

Positive and significant correlations were consistently found for *PWP*, *PSP* and *TRI* from the previous May to the current May. Pearson's correlation coefficient (r) for *CSP* were smaller (< 0.29) and negatives (-0.24, to -0.25) in current April and May, respectively. The graphical results for each of the indices show that Niño 3.4 has the most variable pattern, because it even yielded negative relations between *CSP* and the previous winter values. In contrast, the MEI and MEI.ext exhibited the most consistent and homogenous behavior throughout the 24 studied months. The MEI showed particularly strong correlation with *PWP* and *CSP*, while its correlation with *TRI* was unclear. In general, there was a period of strong correlation from the previous May to the current April between seasonal precipitation and the radial growth of trees (Fig. 2).

Graphs showing the influence of the large-scale atmospheric circulation patterns of ENSO (measured with the three selected indices) on *P* and its effect on tree-radial growth *TRI* are displayed in Figure 3. *PWP* exhibits strong association with ENSO and has an effect on *TRI*. This relation is stronger in the wet years of El Niño and weaker in the dry years of La Niña (Fig. 4).

4. Discussion

Historically, ENSO has been linked with interannual variability of climate over decades and even centuries (Li *et al.*, 2013). There is strong variability at the 3- to 7-year timescale as well as on inter-decadal timescales between 12 and 15 years (Birk *et al.*, 2010). However, our study is the first to use ENSO records over 55 years, and to examine its influence on local climate and the ecological processes of a temperate forest in northern Mexico.

Seager *et al.* (2009) and Méndez-González *et al.* (2007) have previously shown connections between ENSO and precipitation in northern Mexico. Here, we show that the strongest correlations with ENSO are exhibited by *PWP* and *TRI*. This shows a positive relation whereby warm ENSO phases cause increased winter precipitation and subsequent tree growth. According to our results, ENSO is likely to enhance growth of *P. cooperi* via positive effects related to soil moisture in the preceding winter (Figs. 3, 4). Several authors have argued that damp winters contribute to tree growth because the rain is usually of low intensity, which favors high infiltration and low evapotranspiration, resulting in a positive soil water balance

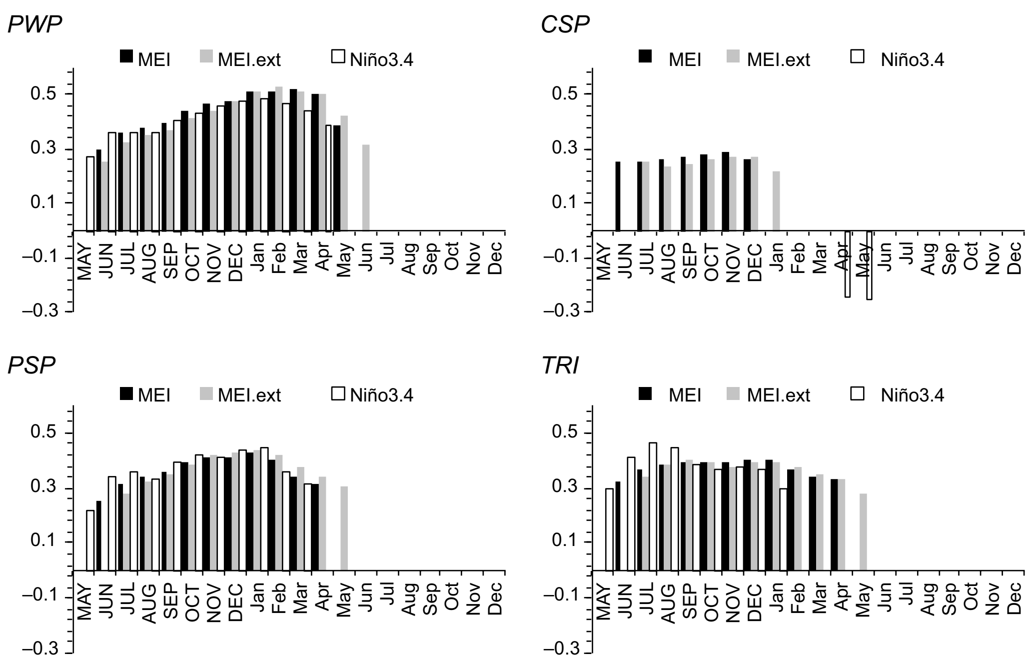

Fig. 2. ENSO index association with seasonal precipitation (*P*) and tree growth (*TRI*) from 1950 to 2005 (statistically significant values $p > 0.05$). *PWP*: previous winter precipitation; *CSP*: current summer precipitation; *PSP*: previous summer precipitation. Lowercase denotes previous year months; uppercase means current year months (regarding the year of tree-ring formation).

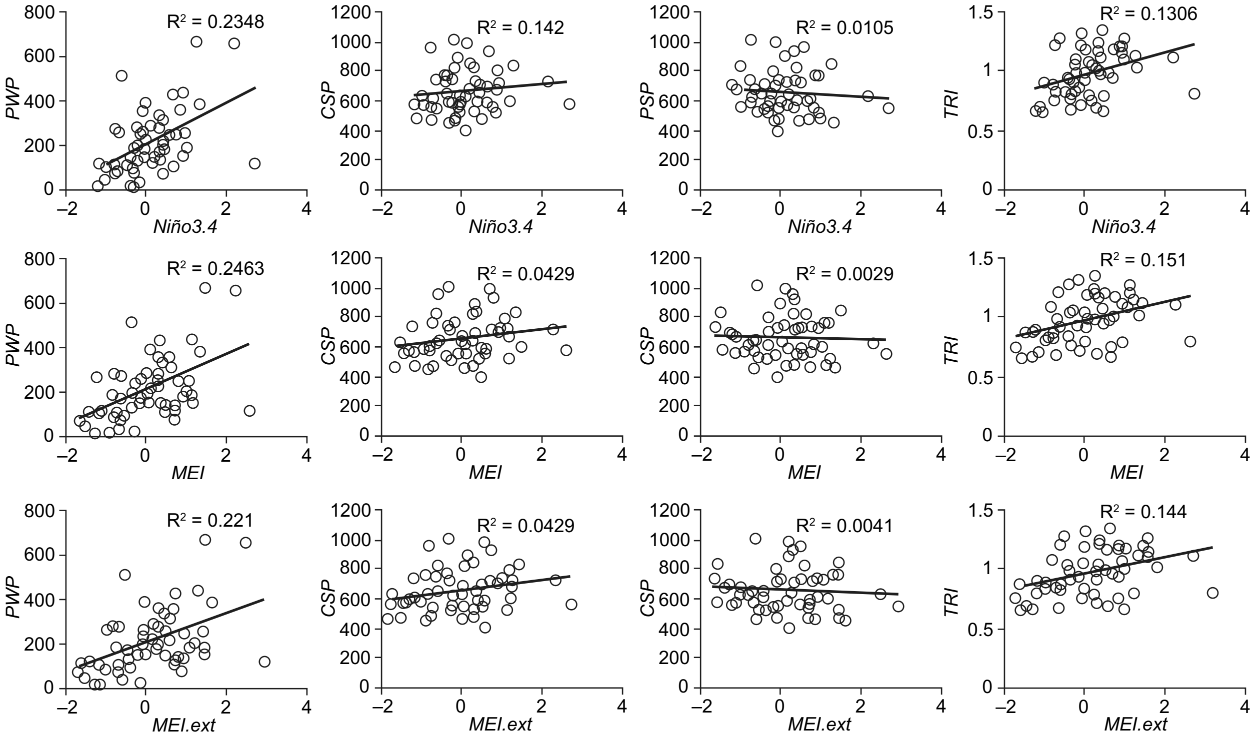

Fig. 3. Correlation of seasonal precipitation (*P*) and tree-ring growth (*TRI*) with ENSO values, expressed as scatter plots.

(Constante-García *et al*., 2009; Pompa-García *et al*., 2013a, 2013b). These findings confirm the hypothesis of Chen *et al.* (2010), who proposed that damp winters contribute to tree growth. In contrast, Meko *et al*. (2013) reported that ENSO affects tree growth via strong monsoon-specific precipitation signals.

Our results show that the correlations between ENSO and the current-summer and previous-summer precipitation are weaker. In summer, ENSO

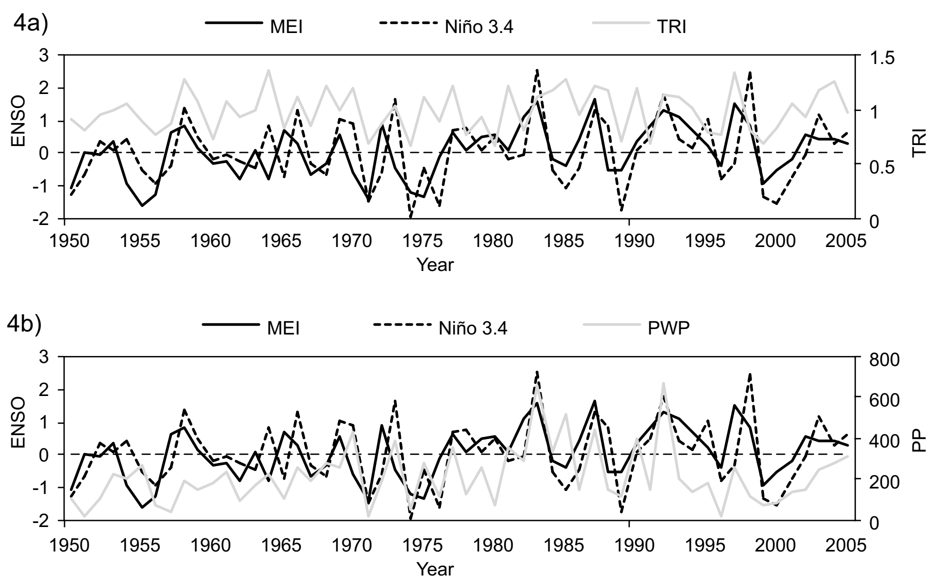

Fig. 4. Comparison between tree ring chronologies of *Pinus cooperi* (a) and ENSO indices (b).

conditions can increase precipitation, but to a lesser extent than in winter, because of the substantial difference between the winter and summer teleconnections to subtropical North America (Seager *et al*., 2009), which can be complicated by the frequent change of ENSO phase between winter and the following summer (Stahle *et al*., 2011). This reveals a clearly marked response between summer and winter, which is important to understand given the strong seasonality of precipitation and ecology within the region (Therrell *et al*., 2004; Griffin *et al*., 2011).

Compared with the MEI and MEI.ext, the relationships in Mexico to the Niño 3.4 index have been studied thoroughly. For example, it has been found that ENSO influences precipitation and runoff in northern Durango (Villanueva-Díaz *et al*., 2007), which agrees with the findings of Cerano-Paredes *et al*. (2011) for the upper basin of the Nazas River. One of the few studies to use the MEI and MEI.ext, performed by Herrera-Cervantes *et al*., (2010), reported that patterns associated with the MEI index vary spatially according to regional topography.

Here we show for Mexico that a strong teleconnection exists between ENSO and monthly precipitation on interannual timescales. Precipitation has the strongest positive teleconnection with ENSO in February, December, and November. In June, August, and September, it has a slightly negative teleconnection with ENSO; while in April, October, and July it shows no relation. Correlation between precipitation and ENSO, measured using the MEI, seems to be stronger in the northern parts of the country, especially near the Pacific Ocean, whereas the negative correlations are located in the south. During the warm phases of ENSO, this causes precipitation to increase in higher latitudes and to decrease in lower latitudes (Méndez-González *et al*., 2007). Furthermore, a preliminary prognosis of the MEI by these authors indicated the likelihood of ENSO to have a stronger effect around the world in years to come. For instance, Seager *et al*., (2012) reported that interannual variability of precipitation minus evaporation becomes stronger in the 21st century compared to the 20th.

The relation between ENSO and climatic change is not yet clear (Li *et al*., 2013). Thus, how best to generate scenarios of regional climate change remains a current research topic that will continue to be debated in the future (Conde *et al*., 2011). A number of authors have recommended evaluating the potential impacts of climate change using techniques such as the principle of maximum entropy (Gay and Estrada, 2010).

Moreover, our findings revealed different responses of *P* and *TRI* to ENSO depending on the ENSO index used; the MEI and MEI.ext indicated the strongest influence, particularly for *PWP* and *TRI*. While all other ENSO indices are fixed geographically, the MEI accounts for the spatial and temporal evolution of climate anomalies within the seasonal cycle (Wolter and Timlin, 2011). Despite this benefit, this means that some inconsistencies can occur because of poor data coverage away from major coastlines (Worley *et al*., 2005). Furthermore, the MEI and MEI.ext are based on multiple variables, rather than just one variable (SST), as in the case of the Niño 3.4 index. Although the MEI has a very limited temporal span, the MEI.ext has achieved reliable measurements for longer time spans (Wolter and Timlin, 2011). The tropical Pacific SST-Mexico precipitation relationship, associated with earlywood and latewood width (Griffin *et al.,* 2011; Meko *et al.,* 2013), could reveal valuable temporal information regarding seasonal precipitation and ENSO variation for the study area.

5. Conclusion

The results presented show clear evidence of the teleconnection of ENSO with local seasonal precipitation and tree growth in northern Mexico. Winter precipitation has a particularly strong correlation to ENSO. Radial growth shows considerable dependence on the climatic conditions of the winter months preceding the growing season and hence, on ENSO conditions. The MEI explains seasonal precipitation and radial growth slightly better than the other indices assessed in this study. As ENSO clearly affects local climate and ecological processes (e.g., radial growth) in northern Mexico, our results constitute a useful predictor of its potential future impact.

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