Changes in the ENSO–rainfall relationship in the Mediterranean California border region

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Abstract
The El Niño-Southern Oscillation (ENSO)–rainfall relationship in the Mediterranean California border region (MCBR) changed recently: considering 30-year running periods (1951–1952 to 1980–1981, until 1986–1987 to 2015–2016) in four stations, ENSO–rainfall correlations ($r$), and mean precipitation ($P$) decreased almost simultaneously. Moreover, $r$ and $P$ appear related throughout the entire record: at the beginning and recently both seem lower than at an intermediate stage. Similar results are found for gridded precipitation data in the vicinity of the MCBR, suggesting that periods of recurrent dry seasons have been less related to ENSO than periods of numerous rainy seasons in this region during the last 65 years.

Keywords: ENSO; California rainfall; changing relationship

1. Introduction
The relationship between El Niño-Southern Oscillation (ENSO) and rainfall in the Mediterranean California border region (MCBR), plus its modulation by decadal variability have been discussed recently (Pavia et al., 2016). In particular, the MCBR has experienced a drought in the last few years, while the ENSO-influence on local precipitation seems to have decreased (e.g. contrary to most cases, the 2010–2011 La Niña was a wet season, and the 2015–2016 El Niño was a dry season). Focusing solely in the ENSO–rainfall relationship, we wonder if the present situation (drought and apparently decreased ENSO-influence in the MCBR’s rainfall) is just a coincidence or it corresponds to wider time- and space-patterns. For example, is the opposite true (wet periods corresponding to strong ENSO-influence on MCBR’s rainfall)? Is this just a recent coincidence or similar situations have occurred before? Is all this exclusive of the MCBR or neighboring regions have experienced similar situations? The purpose of this work is to try to answer these questions, mainly because within the MCBR several major cities are located (Figure 1); but also because we think this study might help elucidate whether the recent drought may be explained in terms of natural variability (Seager et al., 2015), anthropogenic warming (Diffenbaugh et al., 2015), or a combination of both.

2. Data and methods
We use precipitation data from four stations within the MCBR: Los Angeles (LA), San Diego (SD); Tijuana (TJ), and Ensenada (EN) from the National Weather Service and the Mexican Water Authority, and the available gridded data of Livneh et al. (2015). For ENSO we use the El Niño 3.4 index (Nino3.4) from the Physical Science Division of NOAA’s Earth System Research Laboratory. We begin by constructing Nino3.4 and rainfall annual indices (July to June) for the four stations from the 1951–1952 to the 2015–2016 season, as in Pavia et al. (2016). Similarly we construct Nino3.4 and annual indices for the gridded precipitation data from the 1950–1951 to the 2012–2013 season. We use correlation analysis for the entire records ($r_o$) plus for 30-year sliding periods ($r$), for the latter we also calculate annual rainfall mean values ($P$). We calculate the correlations of $P$ and $r$-[$r'$($P$,$r$)] for the gridded and the four stations rainfall data, in the latter case we also fit a straight line to $P$ versus $r$. Finally, we test the statistical significance of all correlation values in terms of their degrees of freedom ($df$) in order to calculate $p$-values; and also to easily identify, with the help of a list of the different periods used (Table 1), the time series used in the correlation analyses by their sample size ($N$), i.e. $N = df + 2$.

3. Results
3.1. Entire period
The map of Nino3.4 and rainfall baseline correlations, from 1950–1951 to 2012–2013, with $df = 61$, for the gridded data are shown in Figure 1(a), for $0.5 < r_o < 0.6$ (red areas) $p_o(0.0001)$. Similarly, baseline correlations, from 1951–1952 to 2015–2016, with $df = 63$, for the four stations are: $r_o = 0.35$, $p_o(0.002)$, for LA; $r_o = 0.49$, $p_o(0.0001)$, for SD; $r_o = 0.45$, $p_o(0.0001)$, for TJ; and $r_o = 0.52$, $p_o(0.0001)$, for EN.

3.2. The 30-year sliding periods
The map of $r'$ from periods 1: 1950–1951 to 1979–1980, to 34: 1983–1984 to 2012–2013,
with df = 32, for the gridded data are presented in Figure 1(b), for \( r’(P, r) > 0.4 \) (red areas) \( p(0.01) \) or better. Time series of \( r \), from periods 2: 1951–1952 to 1980–1981, to 37: 1986–1987 to 2015–2016, and statistical significance levels, with df = 28, for the four stations are presented in Figure 2. For LA, SD, TJ, and EN plots of \( P \) versus \( r \) are presented in Figure 3. A linear fit to each of these four cases yield a positive slope, and \( r’(P, r) \) and statistical significance, with df = 34, are as follows: \( r’ = 0.75, \) for LA; \( r’ = 0.76, \) for SD; \( r’ = 0.83, \) for TJ; and \( r’ = 0.79 \) for EN; all four cases at \( p(<0.0001) \).

### 4. Discussion and conclusions

The relationship between ENSO and rainfall in the continental-coastal region approximately between 31°–35°N, 116°–119°W, labeled here as MCBR, has been recognized for some time (see, e.g. Schonher and Nicholson, 1989; Pavia and Badan, 1998; Fierro, 2014). However, this relationship seems to have weaken recently: correlations between Nino3.4 and gridded rainfall annual indices (from 1950–1951 to 1999–2000) have been declining since. Likewise, in SD, TJ, and EN precipitation mean values \( (P) \) reached a peak in the period 25: 1974–1975 to 2003–2004 (LA in period 24: 1973–1974 to 2002–2003) and also have been declined since. Indeed for gridded data \( r \) and \( P \) are positively correlated and around the region (gray and red color in Figure 1(b)), although some of these correlations are low and non-statistically significant at \( p(0.01) \) (gray color in Figure 1(b)). Similarly, negative correlations are found mostly to the south and east of the MCBR (blue colors in Figure 1(b)); gridded data is used only to get an idea of the spatial pattern of our analyses, and correlation values are used only qualitatively. Plots of \( P \) versus \( r \) for the four stations (Figure 3), all show similar features. In addition to yielding linear-fit positive slopes, the four cases show mostly bluish (early stage periods) and reddish (late stage periods) for lower \( P \) and \( r \), and mostly greenish and yellowish (middle-stage periods) for higher \( P \) and \( r \) (Figure 3); these station data are considered more reliable for specific locations since they have not been spatially interpolated. Nevertheless the qualitatively good agreement between gridded and

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**Table 1.** The 30-year periods used in this study (periods 3–33 not shown).

| Period number | 30-year range          | Gridded data | LA, SD, TJ, and EN |
|---------------|------------------------|--------------|-------------------|
| 1             | 1950–1951 to 1979–1980 | Yes          | No                |
| 2             | 1951–1952 to 1980–1981 | Yes          | Yes               |
| ...           | ...                    | ...          | ...               |
| 34            | 1983–1984 to 2012–2013 | Yes          | Yes               |
| 35            | 1984–1985 to 2013–2014 | No           | Yes               |
| 36            | 1985–1986 to 2014–2015 | No           | Yes               |
| 37            | 1986–1987 to 2015–2016 | No           | Yes               |

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Station data is a robust indication of a positive relationship between \( P \) and \( r \) in this region. Consequently, we conclude that in the MCBR, especially in the zones near the coast, periods of recurrent dry seasons have been less related to ENSO than periods of numerous rainy seasons, at least during the last 65 years. This conclusion (valid for the red areas of Figure 1(b), and the four representative stations in Figure 3) is more in line with the explanation of natural variability, rather than anthropogenic warming, as the cause of the recent MCBR drought, since the present conditions are similar to the conditions at the beginning of our record. The spatial patterns represent the 1950–2013 gridded data record, however the station data show that the present condition has been enhanced in the last couple years, since compared to previous results using 1951–2013 records (Pavia et al., 2016), \( P \) and \( r \) have continued to decrease in all cases but the last two periods (36 and 37) in SD (Figure 2). Although the late 20th century increase in Central Pacific El Niño events (Yeh et al., 2009) may help to explain the strengthening of ENSO–rainfall relationship during the middle-stage periods, it may not explain the early and late stage of the opposite condition. It is also worth noting that the northern-most LA station reports the less statistical significant correlations [e.g. \( r = 0.28, p(0.07) \), for period 37]. Nonetheless, we believe the answer to why extended periods of below-average (above-average) rainfall concur with weak (strong) ENSO–rainfall relationship will be found only by examining sea surface patterns in the Pacific Ocean and elsewhere (Seager et al., 2015). The latter is a task which is obviously beyond the aim of this short contribution, whose goal is rather to incite further research on this topic. As the 2016–2017 La Niña becomes a wet season in the MCBR, ENSO–rainfall correlations would decrease while the drought ameliorates but continues. This result should strengthen our conclusions.

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