The Effect of ENSO on Rainfall in Chile (1964-1990)

Introduction

Chile extends from the Tropic of Capricorn to the Drake Passage. As a consequence, the meteorological and oceanographic stations along this narrow country present several different types of climate, and all of them are affected by the El Niño/Southern Oscillation (ENSO). (Indeed, as you traverse the country from north to south you encounter a remarkable change in the driest desert in the world, the Atacama Desert, to the wetlands of Tierra del Fuego in the south.) It has been known for several years that during El Niño events the country experiences above-average rainfall, whereas during La Niña events the winters are much drier and colder. As a result of ENSO events, the Chilean economy suffers great losses. For example, after three years of lower-than-average rainfall (1988-1990), the generation of power by hydroelectric plants was so low that several thermal electric plants were working full time, with a consequent deterioration of the environment and increase in costs.

In this study, an Empirical Orthogonal Function (EOF) analysis is applied to rainfall data from Chile in order to determine its predominant spatial and temporal patterns. Then, the time series of individual EOFs are compared with sea level at Caldera, which is a good indicator of ENSO events. Figure 1 shows the geographical distribution of the rainfall and tidal stations, and Table 1 gives the geographical location of the stations.

Our statistical analysis indicates that the first and second EOFs account for 82 percent of the variance in the monthly rainfall anomalies and that there is a direct relationship between El Niño events and the amount of rainfall throughout the country. The spatial structure of the second EOF shows that the four southernmost stations should experience less effect during El Niño years. The cross-correlation between sea level at Caldera and the Second EOF time series indicates that there is a 6-month delay from the time that the sea level rises at Caldera (via the arrival of a Kelvin wave from the equator) and the anomalous precipitation.

Description of Data and Statistical Analysis

The precipitation data for this analysis was obtained from the Dirección Meteorológica de Chile in Santiago, Chile. The sea level data was obtained from the Servicio Hidrográfico y Oceanográfico de la Armada in Valparaíso, Chile. Monthly precipitation anomalies were calculated for the 15 stations shown in Figure 1 for the 26-year period from 1965 to 1990, by subtracting the 26-year monthly average from the corresponding monthly value. A similar calculation was done to obtain the sea-level anomalies at Caldera for the period 1951 to 1991.

An EOF analysis was performed on the rainfall anomalies for the 15 stations, yielding a set of 15 rainfall-anomaly spatial patterns (eigenvectors), each associated with a rainfall-anomaly time series. Each spatial pattern is modulated by its time series. The first EOF accounts for 64.3 percent of the variance, and the second for 17.7 percent. Thus, a remarkable total of 82 percent of the variance is in the first two modes. It will be seen that they are both ENSO modes.

The time series of EOF 1, filtered using a 12-month running average, is shown in Figure 2. It is easily recognized as being modulated by an ENSO signal, with large positive anomalies existing in the years 1965, 1969, 1972, 1983, and 1987 in which strong or moderate warm events occurred in the equatorial Pacific. A similar ENSO modulation is found for the time series of EOF 2 (Figure 3), which has large anomalies in the years 1965, 1972, 1975, 1983, and 1987. Conversely, minima in both figures occur during some of the years when strong or moderate cold events occurred. The spatial pattern of EOF 1 (Figure 4) indicates that all stations will behave in the same way for any specific given temporal perturbation. In con-
indicate that the four southernmost stations (Puerto Montt, Osorno, Valdivia and Temuco) will behave oppositely as compared to the other stations.

Figure 6 shows the time series of the mean sea level anomalies (MSLA) at Caldera from 1951 to 1991, after being filtered using a 12-month running average to reduce the seasonal signal. This time series is clearly modulated by an ENSO signal, and it has a distinctive set of low and high peaks related to El Niño and La Niña events. The cross-correlation of MSLA with the EOF-1 time series shows a very poor correlation for a lag/lead period of 12 months (< 0.1) that is not significant. The cross-correlation of MSLA with the EOF-2 time series, however, shows a strong correlation when MSLA leads the EOF-2 time series by 6 months (0.6). Thus, a 6-month delay between MSLA and an anomalous precipitation month exists.

Physically, we expect the sea-level response to arrive from the equator via the propagation of Kelvin waves. The sea-level change disturbs the local heat balance of the ocean off Chile by decreasing the amount of cool upwelled water. Subsequently, teleconnections in the atmosphere from the equator, as well as the modified ocean climate along the Chilean coast, produce perturbations in the precipitation climate for Chile. A delay of 6 months is reasonable.

Discussion
The EOF analysis of rainfall over Chile indicates that the country is divided into three geographical rainfall zones: the Northern Region located from 18°S to 33°S, the Central Region from 33°S to 37°S, and the Southern Region from 37°S to 42°S.

The Northern Region is a very dry zone where the average rainfall is less than 15 mm/yr. At these stations it is not unusual to have years of no precipitation at all. From the spatial distribution of the first and second EOFs, it is clear that the impact of ENSO in this region is almost negligible, with this zone receiving one or two isolated brief rains during a warm ENSO phase.

The Central Region is an area of Mediterranean climate where the average rainfall is around 300-400 mm/yr. In this region the effects of ENSO are most prevalent and can generate the largest losses due to damage to agriculture. The cold phase of ENSO results in colder winters and diminished rainfalls.
that can last up to 2 or 3 years and produce severe droughts. The warm phase of ENSO results in above-average rainfall that can be 2-3 times the annual average and may generate floods.

The Southern Region is an area where the average rainfall is over 1,000 mm/yr. Its climate is much like that of the northwestern states of Oregon and Washington in the United States, but less cold. Because of these distinctive climate characteristics, the impact of ENSO on the region is not as severe as in the Central Region. The spatial distribution of the second-mode EOF shows that an El Niño event will produce a negative rainfall anomaly that tends to cancel a portion of the positive rainfall anomaly of the first-mode EOF, resulting in a less severe positive rainfall
anomaly. During La Niña events, the effect will be the opposite, keeping the resulting negative rainfall anomaly smaller.

To summarize: The cross-correlation analysis shows that there is a strong correlation between MSLA and the time series for EOF2. This correlation coefficient is around 0.6 when there is a 6-month lag of the EOF-2 time series with respect to MSLA. This means that MSLA at Caldera can be used as a physical advisory parameter to forecast rainfall anomalies in the Central and Southern Regions of Chile. The 6-month lag tells us that there is a delay between the ocean responses to ENSO at Caldera that can help planning in advance to prevent or mitigate the effects of this phenomenon over the Chilean ecosystem.

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TOGA Notes