INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **25**: 17–31 (2005)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/joc.1097

EL NIÑO–SOUTHERN OSCILLATION EVENTS AND ASSOCIATED EUROPEAN WINTER PRECIPITATION ANOMALIES

D. POZO-VÁZQUEZ,[a,*] S. R. GÁMIZ-FORTIS,[b] J. TOVAR-PESCADOR,[a] M. J. ESTEBAN-PARRA[b] and Y. CASTRO-DÍEZ[b]
[a] *Departamento Física, Universidad de Jaén, Jaén, Spain*
[b] *Departamento Física Aplıcada, Universidad de Granada, Granada, Spain*

Received 10 August 2003
Revised 23 July 2004
Accepted 26 July 2004

ABSTRACT

The winter precipitation anomalies in the European area have been analysed over the period 1900–98 based on the El Niño–Southern oscillation (ENSO) state. A set of winter and autumn ENSO events is first selected using the Sea-Surface temperature (SST) data of the Niño 3 region, with the constraint that the ENSO event is well developed during the winter and autumn of study, and that it is an extreme event. Cold and warm ENSO events and periods that can be regarded as normal are selected. For the selected winter ENSO events and for the winter following the selected autumn ENSO events, composites of European winter precipitation anomalies have been obtained and compared with each other. A study of the consistency among events of the relationship between ENSO and precipitation anomalies was also carried out. The analysis of the winter precipitation anomalies based on the selected winter ENSO events shows the existence, for the European area and during La Niña events, of a statistically significant precipitation anomaly pattern with positive precipitation anomalies north of the British Isles and in the Scandinavian area and negative anomalies in southern Europe, resembling the precipitation pattern associated with the positive phase of the North Atlantic oscillation (NAO). Particularly, for the southwestern area of the Iberian Peninsula, the negative anomaly reaches 20% of the winter average precipitation. The consistency analysis shows that this precipitation pattern is not the result of a few major events, but rather that it is stable and qualitatively similar to that found during the positive phase of the NAO. A non-linear response to ENSO is found in the eastern Mediterranean area: negative precipitation anomalies are found, having similar amplitude anomalies, both during El Niño and La Niña events. The analysis of the precipitation anomalies for the winter following the selected autumn ENSO events shows very similar results to those found for the previous analysis, thus suggesting the existence of a potential source of seasonal forecasting of European precipitation. An analysis of the sensitivity of the precipitation anomalies to the strength of the ENSO events shows that, when the strength of the ENSO increases, the magnitude of the rainfall anomalies does not change, but the area influenced and the coherence between events do increase slightly.

KEY WORDS: ENSO; Europe; precipitation; seasonal forecasting

1. INTRODUCTION

The El Niño–southern oscillation (ENSO) phenomenon is recognized as a major source for global climate variability (Trenberth *et al*., 1998). The association between ENSO and climate anomalies in the tropical Pacific region, the impact of ENSO on the climate of the extratropical regions, and the mechanism responsible for which anomalies in the tropical Pacific sea-surface temperature (SST) have world-wide impacts have been the subject of numerous studies in recent decades. Nevertheless, the impact of ENSO on the climate of the North Atlantic region remains open to debate (Hurrell *et al*., 2003). The search for ENSO signals in the North Atlantic area presents several difficulties. Firstly, there are different types of El Niño and La Niña events, with different characteristics that can lead to different responses of the extratropical atmospheric circulation.

* Correspondence to: D. Pozo-Vázquez, Departamento de Física, Facultad de Ciencias Experimentales, Campus Las Lagunillas, edif. B3, Universidad de Jaén, 23071, Jaén, Spain; e-mail: dpozo@ujaen.es

Secondly, climatological planetary atmospheric waves, natural noise and the complexity of the numerous feedbacks (and maybe non-linear relationships) can embed and hide the signal of ENSO in the extratropics (Trenberth, 1997a).

On the other hand, seasonal climate forecasting is attracting interest as society attempts to minimize the risk associated with changes in weather conditions. The ability to forecast unusual climate conditions a few months in advance is one of the most potentially important developments in the environmental sciences of current times. Much of this research is based upon the El Niño phenomenon. Although the potential for prediction is much lower in the extratropical regions than in the tropics, recent studies (using dynamical or statistical models) indicate that skilful forecasts may be possible even for the northern extratropical regions (Brankovic and Palmer, 2000; Graham *et al*., 2000; Doblas-Reyes *et al*., 2000; Rodwell and Folland, 2002). Some studies show that predictability in these northern extratropical regions seems to be higher during the ENSO extreme years (Brankovic and Palmer, 2000; Lloyd-Hughes and Saunders, 2002).

There is agreement on the existence of an impact of the ENSO phenomenon on the spring and autumn precipitation in the European area (Rodó *et al*., 1997; Rocha 1999; van Oldenborgh *et al*., 2000; Lloyd-Hughes and Saunders, 2002; Mariotti *et al*., 2002). On the other hand, although several studies discussing the relationship between ENSO and European winter precipitation exist, there is no a general agreement in evaluating the importance of this influence. For instance, Fraedrich and Müller (1992) analysed the climate anomalies in Europe associated with ENSO extremes. During winter cold ENSO events, they found weak positive precipitation anomalies for Scandinavia and negative precipitation anomalies for the western and southwestern parts of Europe. They also found a comparable regional anomalies pattern during El Niño events, but having a reversed sign. Also, Wilby (1993) found an intensification of the North Atlantic storm track, shifted northward from Iceland to northern Europe, and an excess of anticyclonic days over western and central Europe during La Niña events. Mariotti *et al*. (2002) found positive anomalies in central and eastern Europe associated with ENSO events. Kiladis and Diaz (1989) found significant differences in the precipitation in the Iberian Peninsula, with above-normal precipitation during the following winter of the onset year of warm ENSO events when compared with cold ENSO events. Nevertheless, Rocha (1999) did not find a significant influence of ENSO on winter precipitation in the Iberian Peninsula.

In this study we analyse specifically the impact of the ENSO phenomenon on the winter precipitation regime in the European area. This influence would be especially important for the southern part of this area, i.e. for the Mediterranean region. Winter precipitation in this region can account for around 30% of the annual precipitation and presents a very marked interannual variability (Goossens, 1985; Esteban-Parra *et al*., 1998; Serrano *et al*., 1999). This leads to a strong climate-related interannual variability in, for instance, agriculture production, hydroelectric power generation and urban water supplies (Trigo *et al*., 2004). Additionally, the possible relationship between European climate and ENSO can have important implications for seasonal forecasting of European climate and general circulation model (GCM) validation. In particular, considerable effort has been made in the last decade to predict the ENSO state using a multitude of methodologies (physical models, statistical models and mixtures of the two) with considerable success in predicting ENSO indices with lead times from 6 to 12 months (Latif *et al*., 1998).

Our strategy is based on a study of the precipitation anomalies associated with a set of cold and warm ENSO events selected following an optimal procedure in terms of an eventual influence of ENSO in the European area. We analyse these precipitation anomalies, the consistency among events and also their statistical significance. First, we carried out the selection of the ENSO events, following a similar procedure to that used in Pozo-Vázquez *et al*. (2001, in press). Over the period 1900–98, we selected a set of winter cold and warm ENSO events, and also a set of autumn cold and warm ENSO events. Second, we carried out a diagnostic study of the influence of the ENSO phenomenon on the winter precipitation by obtaining and analysing composites of winter precipitation anomalies based on the selected winter ENSO events. Third, we carried out a predictive study of the ENSO–precipitation relationship. Most ENSO events begin between March and September and end between February and March, with the peak of the anomalies during the northern winter (Trenberth, 1997b). Thus, if the ENSO event is well developed during autumn and is an extreme event, then the event persistence to the following winter can be expected in most cases. Therefore, an influence of ENSO on European precipitation anomalies during the winter following an autumn ENSO event should be expected. In this study we explore this hypothesis over the period 1900–98. We do not require information about the state of the ENSO during the winter, so this study gives certain forecasting information concerning the precipitation anomalies during the winter following an autumn ENSO event.

This study is structured as follows. In Section 2 we discuss the criteria for the selection of the autumn and winter ENSO events and the data used in this study. In Section 3.1 we obtain composites of winter precipitation anomalies for the selected winter ENSO events and in Section 3.2 the composites of winter precipitation anomalies based on the selected autumn ENSO events are obtained. In both winter and autumn studies we also investigate the consistency among events of the relationship between ENSO and precipitation. In Section 3.3, we study the dependence of the results of Section 3.1 on the strength of the ENSO events. In Section 4 we conclude with a summary and discussion of the results.

2. METHODOLOGY AND DATA

As commented above, the search for ENSO signals in the North Atlantic area presents several difficulties. Some workers have argued that an ENSO signal in the extratropics can only be found when tropical SST anomalies are large (Huang *et al*., 1998; Trenberth *et al*., 1998). There is a lag of around 3 months between the beginning of an ENSO event and, eventually, the extratropical response in higher latitudes in the North Pacific area (Trenberth and Hurrell, 1994). This response often resembles the Pacific–North American (PNA) pattern. The perturbation can be propagated downstream, as a wave train, to other longitudes in the form of Rossby waves, eventually affecting locations far away from the Pacific, particularly the North Atlantic region. Consequently, the eventual propagation of such events to other longitudes takes place with a similar lag. As we are interested in the ENSO signal in the North Atlantic area during the northern winter, and bearing in mind the PNA hypothesis, we have to select those ENSO events that are considered extreme and that are well developed during the previous autumn. Similarly, for the selection of autumn ENSO events, we have to select those ENSO events that are considered extreme and that are well developed during the previous summer.

In this study, we have used the Niño3 SST region (5 °S–5 °N, 90–150 °W) to monitor ENSO. SST data for the period 1900 to 1998, from the UK Meteorological Office GISST2.3 (Rayner *et al*., 1996), have been used. These data are compiled on a monthly basis, and a monthly standardized index was computed using the reference period 1951–80. Finally, seasonal values are calculated by averaging the corresponding monthly values: June to August for summer, September to November for autumn, and December to February for winter.

A set of extreme ENSO events has been selected basing the analysis on the former seasonal SST normalized series: for El Niño (La Niña) winter events, we selected those years in which current winter and the preceding autumn have an index value roughly equal to or greater than 0.7 times the standard deviation (years in which current winter and the preceding autumn have an index value roughly equal to or less than −0.7 times the standard deviation for La Niña events). Similarly, for El Niño (La Niña) autumn events, we selected those years in which the current autumn and the preceding summer have an index value roughly equal to or greater than 0.7 times the standard deviation (years in which the current autumn and the preceding summer have an index value roughly equal to or less than −0.7 times the standard deviation for La Niña events).

A similar threshold is used by Mason and Goddard (2001). The use of this relatively low-amplitude threshold can be argued given the fact that the tropical east Pacific rainfall suppression during La Niña events tends to saturate and even moderate the amplitude of the cold SST anomalies. Thus, the teleconnection process for moderate and strong events would be quite similar, some evidence for which is shown in the GCM study of Hoerling *et al*. (2001). Figure 1 shows the time series of the Niño3 normalized SST indices for both winter and the preceding autumn, and Figure 2 shows the SST indices for autumn and the preceding summer. The criterion for the preceding summer when selecting the autumn ENSO events ensures that, during the autumn, the ENSO events will be well developed. Similarly, the criterion for autumn when selecting the winter ENSO events ensures that during the following winter the ENSO events will be well developed.

Since our purpose is to study an eventual ENSO-related climatic signal in the North Atlantic area, we must be able to compare the situation during extreme ENSO events with periods that can be regarded as normal.

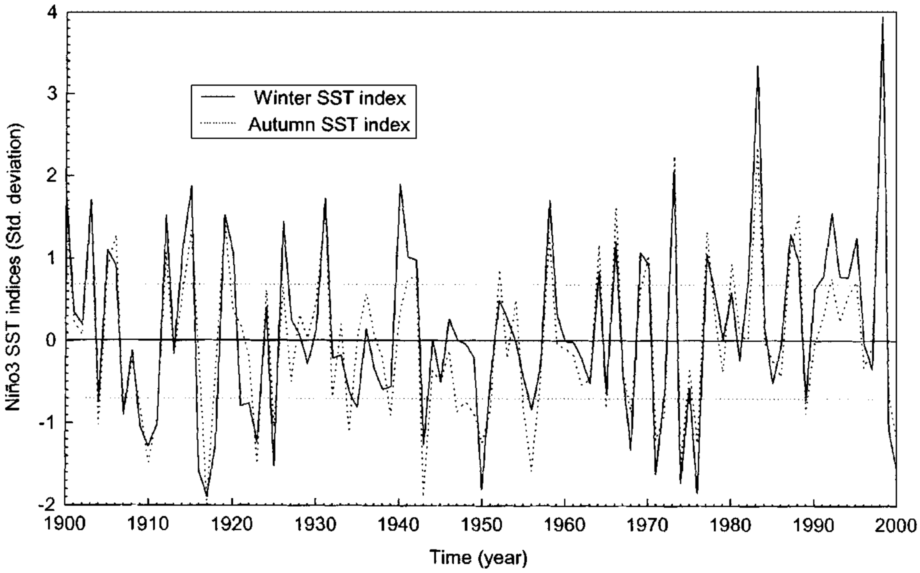

Figure 1. Time series plots of the winter and autumn Niño3 normalized SST indices. Continuous line is the index for winter and dotted line refers to the index of the preceding autumn. Indices are seasonally averaged based on monthly indices normalized to the period 1951–80. The lines corresponding to 0.7 times the standard deviation are also shown

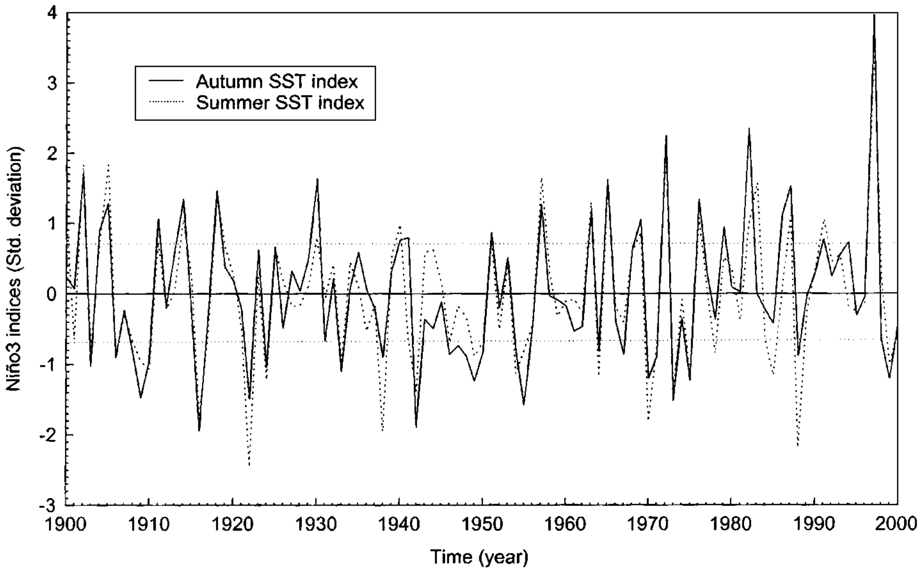

Figure 2. As in Figure 1, but for the autumn and summer Niño3 normalized SST indices. Continuous line is the index for autumn and dotted line refers to the index of the preceding summer

These periods are not necessarily all the years not selected as extreme events. Some ENSO episodes may fulfil one of the criteria, the criterion for winter or the criterion for the preceding autumn for the case of the winter ENSO events (the criterion for autumn or the preceding summer in the case of the autumn ENSO events). We do not regard these years as normal, since they can have some kind of weak effect in winter over the climate of the North Atlantic region. We consider normal years those that fulfil neither of the two criteria and we will refer to these hereinafter as 'normal' years. Tables I and II list the selected cases for winter and autumn respectively. There are 22 El Niño and 19 La Niña events for winter and 19 El Niño and 19 La Niña

Table I. List of El Niño, La Niña and normal selected winter events. The period of analysis is 1900–98. For El Niño (La Niña) years the current winter and the preceding autumn have an SST index value roughly equal to or greater than 0.7 times the standard deviation (less than −0.7 times the standard deviation for La Niña). For normal years the SST index value does not fulfil the criterion for winter or for autumn

El Niño	La Niña	Normal	
1900	1904	1901	1961
1903	1907	1902	1962
1905	1909	1908	1963
1906	1910	1913	1967
1912	1911	1924	1975
1915	1917	1927	1978
1919	1923	1928	1979
1931	1925	1929	1981
1941	1934	1930	1984
1942	1943	1932	1985
1958	1950	1933	1986
1964	1956	1936	1990
1966	1965	1937	1996
1970	1968	1938	1997
1973	1971	1944	
1977	1972	1945	
1983	1974	1946	
1987	1976	1953	
1988	1989	1954	
1992		1957	
1995		1959	
1998		1960	

events for autumn. The selected warm and cold events are consistent with those identified in other empirical studies (Mason and Goddard, 2001; Trenberth, 1997b; Hoerling *et al*., 1997; Kiladis and Diaz, 1989; van Loon and Madden, 1981).

A monthly land-only precipitation dataset of the European area has been analysed. The data are on a 5° latitude by 5° longitude grid basis, covering the period 1900–98, and have been provided by the CRU (Hulme, 1992). The data were normalized; the mean for the period 1900–98 has been subtracted from the monthly values and seasonal averages for winter (December to February) were determined. Additionally, a set of 48 monthly precipitation data series, corresponding to stations which homogeneously cover the Iberian Peninsula, has also been analysed. The data correspond to the 1900–98 period and have been checked for several different quality criteria in previous studies (Esteban-Parra *et al*., 1998).

With these databases, and based on the selected winter and autumn ENSO events, composites of precipitation anomalies during winter were obtained. A Student's t-test was used to compare the means of the composites in each grid. A signal was considered significant when it was significant at the 95% level for a two-tailed test of the null hypothesis of no difference in means. The test was applied to compare the composites of precipitation of the selected El Niño and La Niña events against normal years and to compare El Niño against La Niña events. The test takes into account eventual different lengths of the series compared. Additionally, a field significance test, taking into account the spatial correlation of the data, i.e. the dependence between the data, has been carried out. In particular, the global field significance of the precipitation patterns was examined following Livezey and Chen (1983).

Table II. List of El Niño, La Niña and normal selected autumn events. The period of analysis is 1900–98. For El Niño (La Niña) years the current autumn and the preceding summer have an SST index value roughly equal to or greater than 0.7 times the standard deviation (less than −0.7 times the standard deviation for La Niña). For normal years the SST index value does not fulfil the criterion for autumn or for summer

El Niña	La Niña	Normal	
1902	1903	1901	1945
1904	1906	1907	1952
1905	1909	1912	1953
1911	1910	1913	1956
1914	1916	1915	1958
1918	1922	1917	1959
1930	1924	1919	1960
1940	1933	1920	1961
1951	1938	1921	1962
1957	1942	1923	1966
1963	1949	1925	1968
1965	1954	1926	1974
1969	1955	1927	1977
1972	1964	1928	1980
1976	1970	1929	1981
1982	1971	1931	1984
1987	1973	1932	1989
1991	1975	1934	1990
1997	1988	1935	1992
		1936	1993
		1937	1995
		1939	1996
		1943	1998
		1944	

For completion of the composite analysis, we have examined the consistency among events in the relationship between the ENSO and precipitation anomalies. The magnitude of anomalies can vary greatly between events, and this could lead to composites dominated by a few major events. It is thus necessary to ascertain the extent to which the signal at a given place is consistent among events. We have addressed this problem by calculating the percentage of consistent signals, defined as the percentage of events having anomalies with the same sign as that of the composite anomaly.

The values of the NAO index were also analysed based upon the ENSO state. A winter index (Hurrell, 1995) was used to monitor the NAO during the period 1900–98. The index was formulated using pressure data from the Azores and Iceland, being normalized relative to the period 1864–1984.

3. ANALYSIS

3.1. Winter precipitation patterns based on the winter ENSO state

Composites of precipitation anomalies during the winters of the selected ENSO events (Table I) have been obtained for the period 1900–98; see Figure 3. We have also obtained the consistency among events

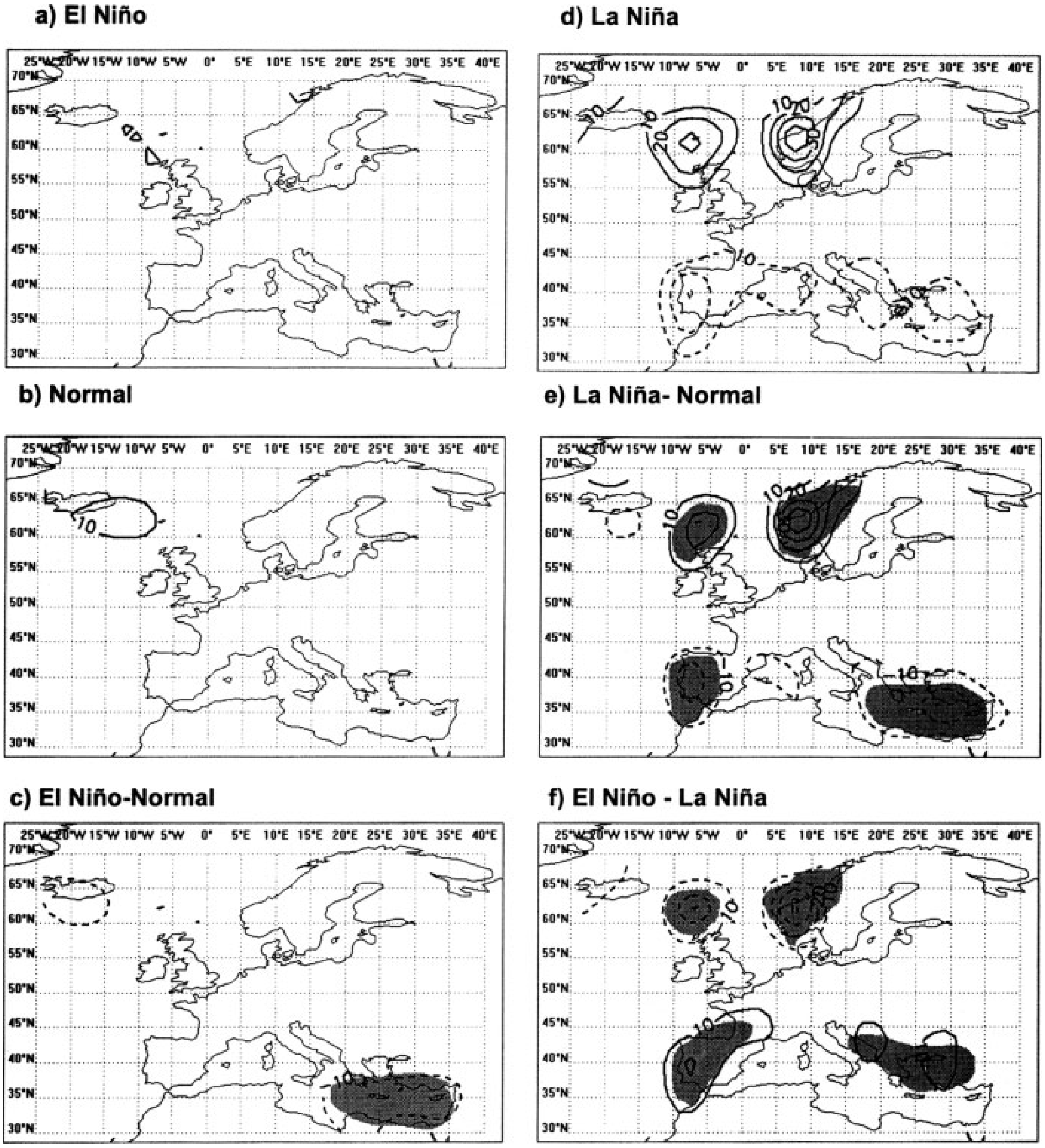

Figure 3. Composites of the observed winter precipitation anomalies during the winters of ENSO events. See Table I for the years included in the composites. (a) During winters of El Niño events, (b) during normal and (c) difference of (a) minus (b). (d) Anomalies during winters of La Niña events, and (e) difference of (d) minus (b). (f) Difference between El Niño and La Niña, (a) minus (d). Contour interval is 10 mm. Continuous line indicates positive or zero anomalies and dotted line indicates negative anomalies. Shading indicates local statistical significance of the difference at the 95% confidence level, based on a t-test

in the relationship between the ENSO and precipitation by calculating the percentage of consistent signals. Figure 4(a) and (b) respectively show the results for El Niño and La Niña.

During El Niño cases (Figure 3(a)) there is not a clear ENSO signal in European regional precipitation, but there are some statistically significant anomalies found in the Mediterranean area, of value around −10 mm, when comparing El Niño and normal patterns (Figure 3(c)). Consistency among events (Figure 4(a)) is high (between 80 and 90%).

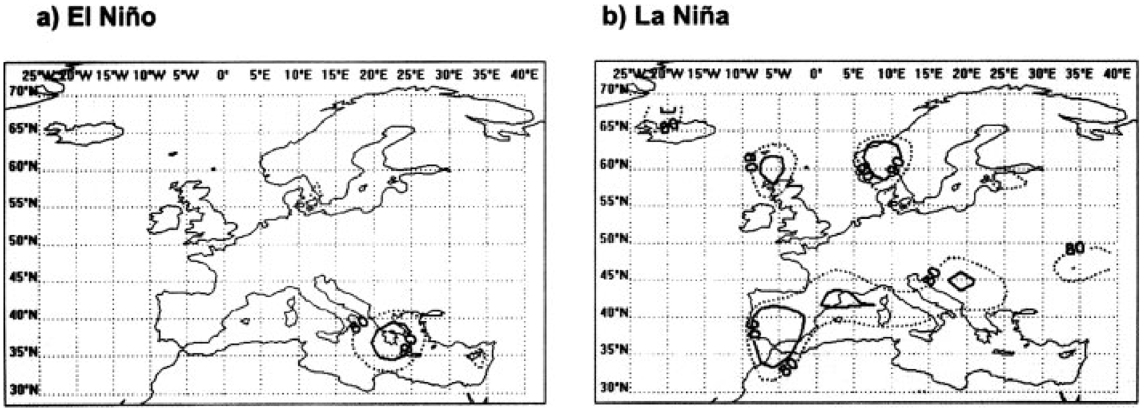

Figure 4. Study of the consistency among events of the relationship between the ENSO and winter precipitation anomalies during the winters of ENSO events. (a) The percentage of events having anomalies with a sign consistent with the composite anomaly for El Niño events; (b) as (a), but for La Niña events. Dotted line indicates 80% and continuous line indicates 90%

During La Niña (Figure 3(d)) a relatively strong precipitation anomaly pattern is found over the study area. There are positive precipitation anomalies over the Scandinavian area and north of the British Isles, reaching up to +40 mm. On the other hand, over the Iberian Peninsula and the eastern Mediterranean area, negative anomalies of up to −30 mm are found. All these areas show statistical significance when compared with the normal situation (Figure 3(e)), and they also show a very high coherence, up to 90% (Figure 4(b)).

The global field significance of the patterns in Figure 3(c) and (e) was examined. A series of 1000 Monte Carlo composite patterns was first obtained in which 20 samples were selected randomly among all the years. It was found that 5% of these patterns had more than 7.8% of their area exceed the 95% confidence level of a t-test when compared with the normal cases composite. Since the La Niña composite in Figure 3(e) was found to have 14% of their area significant when compared to the normal composites, the spatial pattern in Figure 3(e) does indeed pass the field significance test at the 95% confidence level. On the other hand, the El Niño composite in Figure 3(c) does not pass the field significance test, since only 5.7% of their area is statistically significant.

Several studies concerning recent decades (Hurrell, 1995; Hurrell and van Loon, 1997; Osborn *et al.*, 1999) have established a clear influence of the NAO on the precipitation in the European region. In particular, the positive phase of the NAO has been associated with positive anomalies in northern Europe and negative anomalies in southern Europe. The precipitation patterns in Figure 3(d) and (e) closely resemble that associated with the positive phase of the NAO in Europe (e.g. see Hurrell and van Loon, (1997: Figures 13 and 14)) and is consistent with the positive-NAO-like sea-level pressure (SLP) anomaly pattern found in the North Atlantic region during La Niña events (Pozo-Vázquez *et al.*, 2001).

We have analysed the value of the NAO index during the ENSO events. Composite values of the winter NAO index were calculated for El Niño, La Niña and normal cases for the selected winter ENSO events in Table I. For La Niña years, the mean value of the NAO index was 0.71, for El Niño it was −0.14 and for normal cases it was −0.16. The mean of the NAO index for the period 1864–1984 (the normalization period) is 0.09. The difference between the composite value for La Niña and normal years is statistically significant at the 95% confidence level using a t-test. Also statistically significant at the 95% level is the difference between La Niña and El Niño years, whereas the difference between El Niño and normal years is not significant.

The strong coherence between events found in Figure 4(b) suggests that the precipitation anomaly patterns over the European area in Figure 3(d) and (e) are not the result of a few major events, but rather because the precipitation anomaly patterns in this area during the winters of cold ENSO events are quite stable and qualitatively similar to those found during the positive phase of the NAO.

Finally, Figure 3(f) shows the difference between El Niño and La Niña. Statistically significant areas are, fundamentally, those found in Figure 3(e).

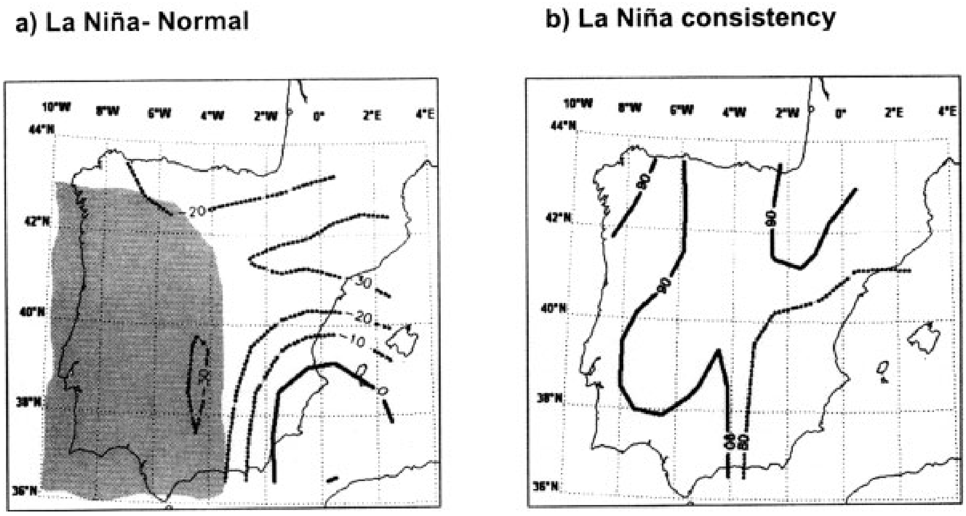

Figure 5. (a) Difference between La Niña and normal composites for the precipitation in the Iberian Peninsula during winters of ENSO events (Table I). Values are percentages of change in precipitation; reference period is 1900–98. Continuous line indicates positive or zero anomalies and dotted line indicates negative anomalies. Shading indicates local statistical significance of the difference at the 95% confidence level, based on a *t*-test. (b) Percentage of events having anomalies with a sign consistent with the composite anomaly for La Niña events. Dotted line indicates 80% and continuous line indicates 90%

In the previous analysis, significant precipitation anomalies in the European area have been found to be associated with ENSO events. The absolute anomaly values are not large compared with tropical regions, but the impact is relevant especially for the region around the Mediterranean, where rainfall is scarce. In previous analysis, the Iberian Peninsula was shown to be one of the areas most sensitive to ENSO. A high-resolution precipitation dataset of this area has been analysed. To highlight the importance of the ENSO on the precipitation in this region, the data have been converted to percentage anomalies from the long-term mean (1900–98) and, then, composites of percentage precipitation anomalies were computed based on the selected ENSO events. Figure 5(a) shows the difference between the La Niña and normal events' composites, and Figure 5(b) shows the percentage consistency among events. Figure 5(a) shows a considerable variability in the Iberian Peninsula: the maximum anomalies are found in the southwestern and central parts, where a decrease of between 20 and 30% can be expected during the La Niña events, having around 90% consistency among events. The northern and eastern parts show lower anomalies. During El Niño events (not shown) no significant anomalies were found. Precipitation anomaly values (not shown) are consistent with those shown in Figure 3(a) and (d).

3.2. Winter precipitation patterns based on the autumn ENSO state

In this section, a somewhat predictive study of the ENSO–precipitation relationship is carried out. Composites of winter precipitation anomalies are obtained based on the selected autumn ENSO events in Table II; i.e. the precipitation anomalies in the European area during the winters following autumns of ENSO events are studied. Information about the state of the ENSO during the winter is not required, so this study gives certain forecasting information concerning the precipitation anomalies during the winter following an autumn ENSO event. Figure 6(a) shows the difference between El Niño and normal cases, and Figure 6(b) between La Niña and normal cases. The consistency among events in the relationship between ENSO and precipitation is shown in Figure 7(a) and (b) for El Niño and La Niña respectively.

When comparing El Niño and normal composites (Figure 6(a)), a statistically significant negative anomaly pattern (reaching −20 mm) is found in the eastern Mediterranean area. Furthermore, this pattern shows a very high coherence, up to 90% (Figure 7(a)). When comparing La Niña and normal cases (Figure 6(b)), a similar pattern to that shown in Figure 3(e) is found: positive anomalies are found over the Scandinavian area

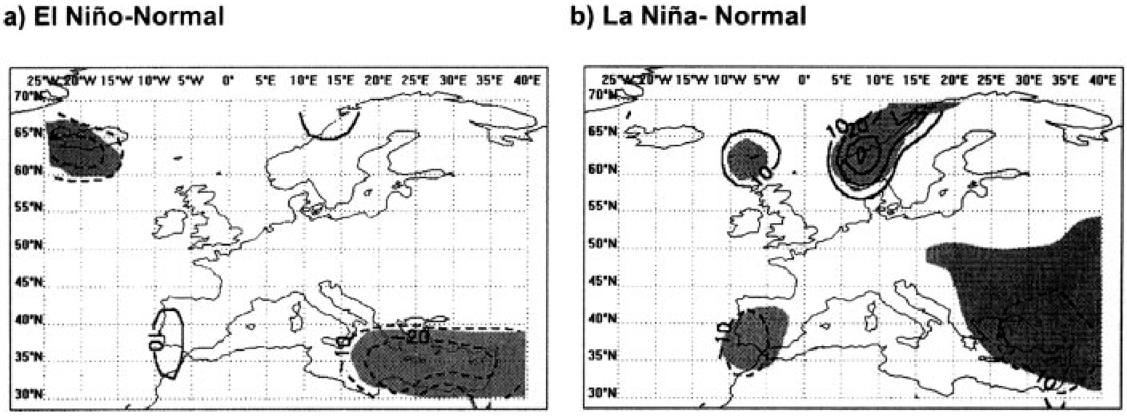

Figure 6. Composites of the observed winter precipitation anomalies during the winters following autumns of ENSO events. See Table II for the years included in the composites. (a) Difference between El Niño and normal composites. (b) Difference between La Niña and normal composites

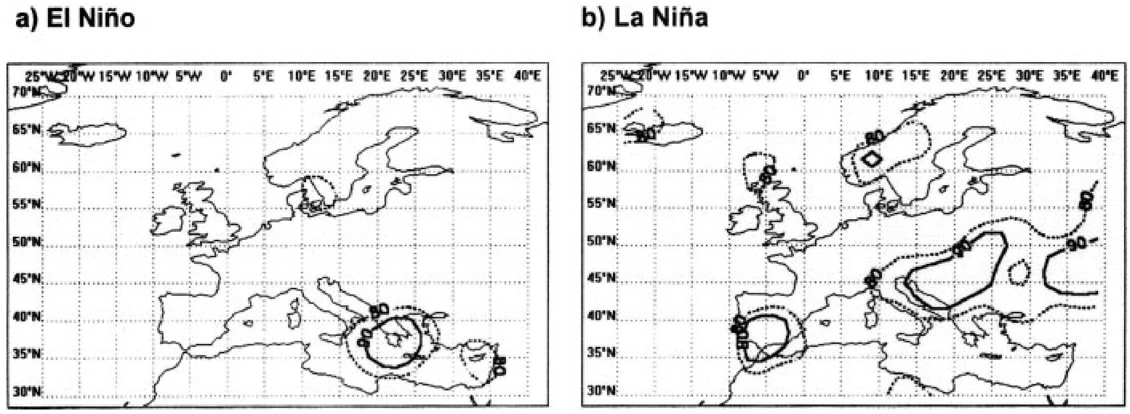

Figure 7. As Figure 4, but for the winters following autumns of ENSO events. (a) The percentage of events having anomalies with a sign consistent with the composite anomaly for El Niño events; (b) as (a), but for La Niña events

and north of the British Isles, whereas negative anomalies are found over the Iberian Peninsula, the eastern Mediterranean area and central Euroasiatic continent. All these areas show statistical significance and a very high coherence, up to 90% (Figure 7(b)).

As in the previous section, a field significance test has been carried out. A series of 1000 Monte Carlo composite patterns was first obtained in which 19 samples were selected randomly. It was found that 5% of these patterns had more than 6.7% of their area exceed the 95% confidence level of the t-test when compared with the normal cases' composites. As both El Niño and La Niña composites were found to have greater than 6.7% of their area (15% for El Niño and 21% for La Niña) exceed the above requirements for a t-test when compared with the normal composites, each of the spatial patterns in Figure 6(a) and (b) does indeed pass the field significance test at the 95% confidence level.

The analysis of the NAO index during the winters following the selected autumn ENSO events in Table II shows for La Niña years a 0.62 composite value, −0.08 for El Niño and −0.03 for normal cases. The differences between the composite value for La Niña and normal years, and for El Niño and La Niña years are statistically significant at the 95% confidence level, whereas the difference between El Niño and normal years is not significant.

As in the previous section, a regional study has been carried out for the Iberian Peninsula. Composites of percentage of anomalies for the selected events in Table II, along with the percentage of coherence between

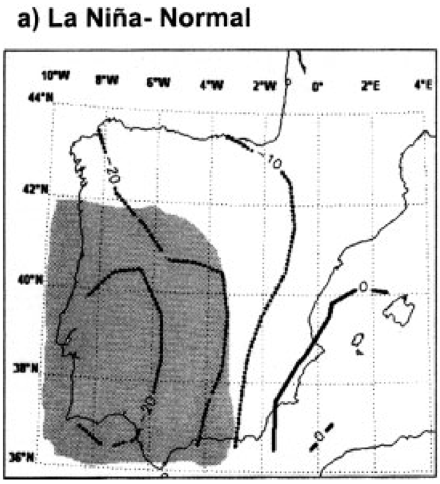

Figure 8. As in Figures 5, but for the precipitation anomalies during the winters following autumns of ENSO events. See Table II for the years included in the composites. (a) Difference between La Niña and normal composites. (b) Percentage of events having anomalies with a sign consistent with the composite anomaly for La Niña events

events, have been obtained. Differences between the La Niña and normal events' precipitation composites for the winter following an autumn ENSO event are displayed in Figure 8(a). Maximum negative anomalies (20%) are found in the southwestern and central parts of the Iberian Peninsula, having around 80% of consistency among events (Figure 8(b)). The northern and eastern parts show lower anomalies. Overall, the results are similar to those shown in Figure 5, but the magnitudes of both the percentage anomalies and the coherence are slightly lower.

3.3. Sensitivity of the precipitation anomaly patterns to the strength of the ENSO signal

In Section 2 we used a 0.7 threshold for the SST index to obtain the ENSO events. An important issue is to know the sensitivity of the European area precipitation anomalies to the strength of the ENSO events, especially when taking into account the relatively weak anomalies found for most parts of the study area. We have addressed this question by obtaining the precipitation anomaly patterns associated with a set of ENSO events selected using the same procedure explained in Section 2, but using, firstly, a 0.9 standard deviation threshold (more stringent than the 0.7 threshold used in Section 2) and, secondly, a 0.5 threshold.

When using the 0.9 amplitude threshold, the 1905, 1941, 1942, 1964, 1992 and 1995 El Niño events, and the 1904, 1907, 1909, 1934, 1956, 1965, 1968, 1972 and 1989 La Niña events listed in Table I are not selected. As a consequence, a considerable reduction in the sample size (around one-third for the El Niño events and one-half for the La Niña events) takes place. Figure 9(a) and (b) shows the differences between the El Niño and normal and between the La Niña and normal winter precipitation composite anomalies; Figure 10(a) and (b) shows the corresponding coherence among events. The main result is, as noted earlier by Mariotti *et al*. (2002), that the strength of the ENSO events does not seem to have a significant influence on the magnitude of the rainfall anomalies; on the other hand, the area influenced by ENSO (and also its coherence between events) seems to increase slightly as the strength of the ENSO events increases.

When using the 0.5 threshold, a set of new El Niño (1914, 1926, 1952, 1969, 1980 and 1994) and La Niña (1934, 1939, 1965 and 1974) events is now selected, in addition to those shown in Table I. The anomalies and coherence patterns (not shown) show a similar spatial pattern to those shown in Figures 3 and 4, but the anomalies are considerable weaker. In particular, coherence between events is lower than 70% over the whole study area and the precipitation anomalies during La Niña in the eastern Mediterranean region disappear.

Therefore, it seems that the 0.7 threshold is an adequate choice to study the influence of the ENSO phenomenon in Europe, as this threshold is a trade-off between the requirement for relatively strong events

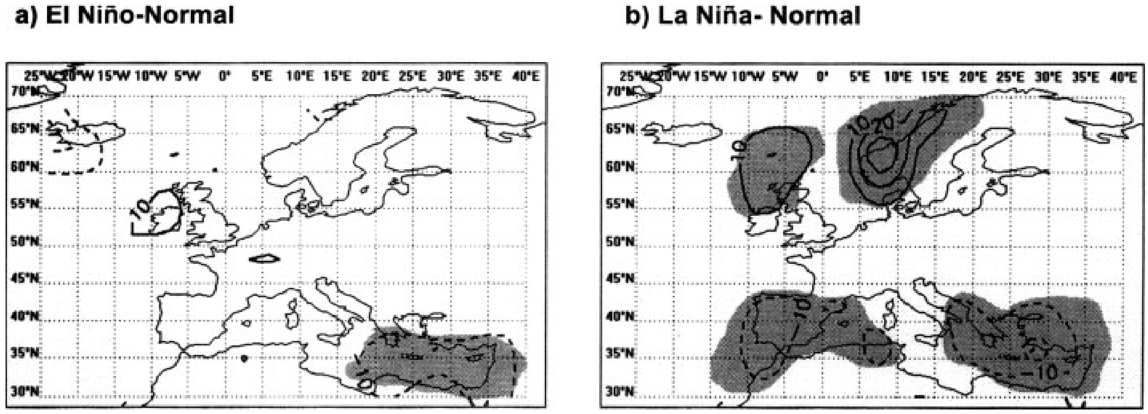

Figure 9. Composites of the observed winter precipitation anomalies during the winters of ENSO events selected using a 0.9 threshold: (a) difference between El Niño and normal composites; (b) difference between La Niña and normal composites. Continuous line indicates positive or zero anomalies and dotted line indicates negative anomalies

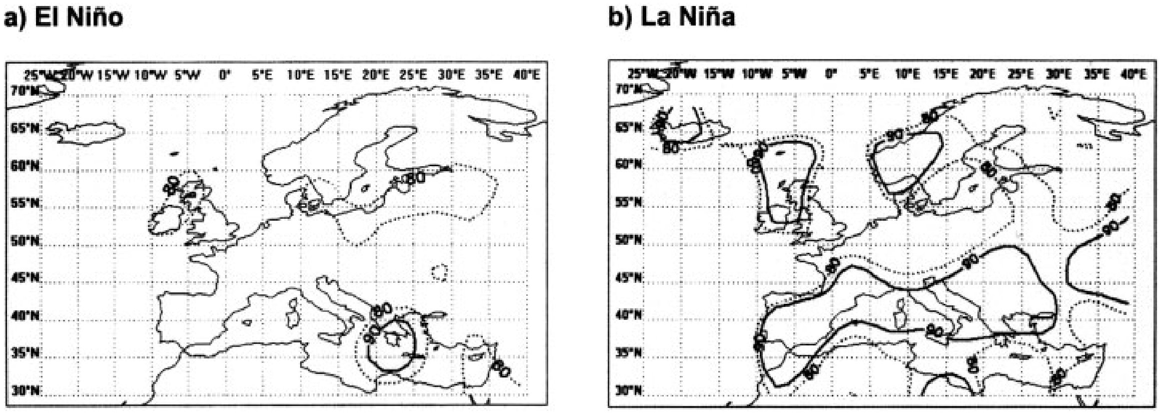

Figure 10. As in Figure 4, but for the selected ENSO events using a 0.9 threshold

to have an impact on Europe and the necessity of avoiding a too stringent threshold that would unnecessarily reduce the sample size.

4. DISCUSSION AND CONCLUDING REMARKS

4.1. Summary

The association between ENSO and winter precipitation anomalies in the European region has been analysed during the period 1900–98. A set of winter and autumn ENSO events was first selected, with the constraint that the ENSO event is well developed during the winter and autumn of study, and that it is an extreme event. For the selected winter ENSO events and for the winters following the selected autumn ENSO events, composites of European precipitation anomalies have been obtained.

The analysis of the winter precipitation anomalies based on the selected winter ENSO events shows the existence, for the European area and during La Niña events, of a statistically significant precipitation anomaly pattern resembling that associated with the positive phase of the NAO. A consistency analysis shows that this pattern is not the result of a few major events, but rather that the precipitation anomalies during cold ENSO events are stable and qualitatively similar to those found during the positive phase of the NAO. A composite analysis of the NAO index provides further evidence of this result. The precipitation response to ENSO in the eastern Mediterranean area is a non-linear one: both during El Niño and La Niña events, negative precipitation anomalies are found, having similar amplitude anomalies and very high coherence. The analysis of the precipitation anomalies for the winters following autumns of La Niña events shows very similar results to those found for the winter analysis, thus suggesting a potential source of climate prediction for the European area.

An analysis of the sensitivity of the precipitation anomalies to the strength of the ENSO events shows that, when the strength of the ENSO increases, the magnitude of the rainfall anomalies does not change, but that the area influenced and the coherence between events do increase slightly.

4.2. *Discussion*

We have previously studied the winter SLP anomalies patterns associated with strong ENSO events (Pozo-Vázquez *et al*., 2001, in press) and found a significant SLP anomalies pattern, resembling the positive phase of the NAO, in the North Atlantic region and during cold ENSO events. The results of this former winter precipitation analysis are consistent with this positive-NAO-like SLP anomaly pattern, and are in agreement with the results of Fraedrich and Müller (1992), Wilby (1993) and Kiladis and Diaz (1989) as far as La Niña events are concerned. On the other hand, we did not find a significant influence of El Niño events on the precipitation of central and northern Europe, but did for the eastern Mediterranean region.

Regarding the predictive study of the ENSO–precipitation relationship, the comparison of the selected winter (Table I) and autumn (Table II) ENSO events shows that, in most cases, the selected events for autumn are also present during the following winter. Just the 1951 El Niño event and the La Niña 1938 and 1954 events were selected during the autumn but not during the following winter. The reason is that the SST anomalies during these years are of lower amplitude than that we have used as a threshold. These anomalies are close to our threshold value and could be also considered for our analysis (for instance, the SST anomaly for the winter of 1933–34 was −0.62, close to our −0.7 threshold; units are standard deviations). This may indicate that the existence of the positive-NAO-like precipitation anomalies in the European area during the winters following autumns of extreme cold ENSO events could just be due to the ENSO event persisting for the following winter, thus affecting the climate in the way indicated by Pozo-Vázquez *et al*. (2001, in press). In particular, for the precipitation anomalies and during cold events, a positive-NAO-like precipitation pattern should be expected. Additional evidence for this hypothesis is presented by Larkin and Harrison (2002), who showed that the cold ENSO events tend to be fully developed between August and December of the year following the year of the first anomalies, whereas the anomalies tend to decay between January and May of the following year. Thus, if the cold ENSO event is well developed during autumn and is an extreme event, then the event's persistence into the following winter can be expected in most of the cases.

Mariotti *et al*. (2002) found a seasonally varying association for the ENSO–precipitation relationship in the western Mediterranean area. In particular, they found a positive correlation between the El Niño 3.4SST index and the October–December precipitation, and a negative one between the SST index and the January–March (JFM) precipitation. Additionally, in two recent studies, Moron and Plaut (2003) and Moron and Gouirand (2003) analysed the influence of ENSO on circulation patterns in the North Atlantic area. One of their main conclusions is the existence of a seasonal modulation of the ENSO signal in the North Atlantic area. In particular, the associated ENSO SLP pattern in this area seems to change from November–December (ND) to JFM. Then they suggest that the best seasonal pooling to study the ENSO influence in the European area is ND and JFM instead of the traditional December–February. We have addressed this issue by obtaining the precipitation composites for each month from November to March (not shown), based on the selected winter ENSO events listed in Table I. The pattern obtained for December and February is very similar to that found for the winter average, whereas the January pattern shows some differences when compared with the winter average pattern. The maximum amplitude anomalies are found during December. On the other hand, November and March show completely different patterns compared with the December and February patterns. It seems that there is a seasonal, and even monthly, modulation of the ENSO impact on precipitation, derived from the seasonal modulation on the SLP patterns. The best way of coping with this problem is probably by studying the ENSO impact on the European climate using a monthly basis. However, ENSO variability is better found in the northern extratropical regions when averages can be taken over the entire winter part of the year instead of when monthly data are used (Trenberth and Hurrell, 1994). This is because noise associated with natural weather variability is higher on monthly time scales. Other issues that must be taken into account when analysing ENSO impact on Europe are the possible existence of decadal variability of the ENSO teleconnections (Diaz *et al*., 2001), and the evidence showing that the impact of ENSO on extratropical variability may differ substantially from ENSO event to event, especially in the northern Atlantic and over Europe (Compo *et al*., 2001).

Our analysis suggests the preference for a positive-NAO-like precipitation pattern in the European region during the winters of cold ENSO events and during the winters following the autumn of strong cold ENSO events, and this suggests the existence of a potential source of predictability for the European climate. Nevertheless, the judgement of the possible significance of this source of predictability and its physical basis, founded just on the observational record analysed, is difficult and must await further analyses with GCMs and other observational records.

ACKNOWLEDGEMENTS

The Spanish CICYT, projects REN2001-3890-C02-02/CLI and REN2001-3923-C02-01/CLI, financed this study. NAO index data were provided by the Climate Analysis Section, NCAR, Boulder, USA. The UKMO GISST 2.2 data were kindly provided by the British Atmospheric Data Centre, Rutherford Appleton Laboratory, Chilton, Oxon OX11 0QX, UK. The precipitation data correspond to the ‘g55wld0098.dat’ (Version 1.0) dataset, constructed and supplied by Dr Mike Hulme at the Climatic Research Unit, University of East Anglia, Norwich, UK. We would like to acknowledge the very helpful comments made by two anonymous reviewers, which helped to improve the manuscript substantially.

REFERENCES

Brankovic C, Palmer TN. 2000. Seasonal skill and predictability of ECWMF PROVOST ensembles. *Quarterly Journal of the Royal Meteorological Society* **126**: 2035–2067.

Compo GP, Sadeshmukh PD, Penland C. 2001. Changes of subseasonal variability associated with El Niño. *Journal of Climate* **14**: 2256–3374.

Diaz H, Hoerling M, Eischeid J. 2001. ENSO variability, teleconnections and climate change. *International Journal of Climatology* **21**: 1845–1862.

Doblas-Reyes FJ, Déqué M, Piedelivre J. 2000. Multi-model spread and probabilistic seasonal forecast in PROVOST. *Quarterly Journal of the Royal Meteorological Society* **126**: 2069–2087.

Esteban-Parra MJ, Rodrigo FS, Castro-Díez Y. 1998. Spatial and temporal patterns of precipitation in Spain for the period 1880–1992. *International Journal of Climatology* **18**: 1557–1574.

Fraedrich K, Müller K. 1992. Climate anomalies in Europe associated with ENSO extremes. *International Journal of Climatology* **12**: 25–31.

Goossens C. 1985. Principal component analysis of the Mediterranean rainfall. *International Journal of Climatology* **5**: 379–388.

Graham RJ, Evans AD, Mylne KR, Harrison MS, Robertson KB. 2000. An assessment of seasonal predictability using general circulation models. *Quarterly Journal of the Royal Meteorological Society* **126**: 2211–2240.

Hoerling MP, Kumar A, Zhong M. 1997. El Niño, La Niña and the nonlinearity of their teleconnections. *Journal of Climate* **10**: 1769–1786.

Hoerling MP, Kumar A, Xu TY. 2001. Robustness of the nonlinear climate response to ENSO’s extreme phases. *Journal of Climate* **14**: 1277–1293.

Huang J, Higuchi K, Shabbar A. 1998. The relationship between the North Atlantic oscillation and El Niño–southern oscillation. *Geophysical Research Letters* **25**: 2707–2710.

Hulme M. 1992. A 1951–80 global land precipitation climatology for the evaluation of general circulation models. *Climate Dynamics* **7**: 57–72.

Hurrell JW. 1995. Decadal trends in North Atlantic oscillation and relationship to regional temperature and precipitation. *Science* **269**: 676–679.

Hurrell JW, van Loon H. 1997. Decadal variations in climate associated with the North Atlantic oscillation. *Climatic Change* **36**: 301–326.

Hurrell JW, Kushnir Y, Ottersen G, Visbeck M. 2003. An overview of the North Atlantic oscillation. *The North Atlantic Oscillation: Climate Significance and Environmental Impact*, Hurrell JW, Kushnir Y, Ottersen G, Visbeck M (eds). *Geophysical Monograph Series* **134**: AGU: Washington, D.C; 1–36.

Kiladis N, Diaz HF. 1989. Global climatic anomalies associated with extremes of the southern oscillation. *Journal of Climate* **2**: 1069–1090.

Larkin NK, Harrison DE. 2002. ENSO warm (El Niño) and cold (La Niña) event life cycles: ocean surface anomaly patterns, their symmetries, asymmetries, and implications. *Journal of Climate* **15**: 1118–1140.
Latif M, Anderson D, Barnett T, Cane M, Kleeman R, Leetman A, O'Brien J, Rosati A, Schneider E. 1998. A review of the predictability and prediction of ENSO. *Journal of Geophysical Research* **103**: 14 375–14 393.
Livezey RE, Chen WY. 1983. Statistical field significance and its determination by Monte Carlo techniques. *Monthly Weather Review* **111**: 46–59.
Lloyd-Hughes B, Saunders MA. 2002. Seasonal prediction of European spring precipitation from El Niño–southern oscillation and local sea-surface temperatures. *International Journal of Climatology* **22**: 1–14.
Mariotti A, Zeng N, Lau KM. 2002. Euro-Mediterranean rainfall and ENSO — a seasonally varying relationship. *Geophysical Research Letters* **29**: DOI 10.1029/20001GL014248.
Mason SJ, Goddard L. 2001. Probabilistic precipitation anomalies associated with ENSO. *Bulletin of the American Meteorological Society* **82**: 619–638.
Moron V, Gouirand I. 2003. Seasonal modulation of the El Niño–southern oscillation relationship with sea-level pressure anomalies over the North Atlantic in October–March 1873–1996. *International Journal of Climatology* **23**: 143–155.
Moron V, Plaut G. 2003. The impact of El Niño–southern oscillation upon weather regimes over Europe and the North Atlantic during boreal winter. *International Journal of Climatology* **23**: 363–379.
Osborn TJ, Briffa K, Tett SFB, Jones PD, Trigo R. 1999. Evaluation of the North Atlantic oscillation as simulated by a climate model. *Climate Dynamics* **15**: 685–702.
Pozo-Vázquez D, Esteban-Parra MJ, Rodrigo FS, Castro-Díez Y. 2001. The association between ENSO and winter atmospheric circulation and temperature in the North Atlantic region. *Journal of Climate* **16**: 3408–3420.
Pozo-Vázquez D, Gámiz-Fortis SR, Tovar-Pescador J, Esteban-Parra MJ, Castro-Díez Y. In press. North Atlantic winter SLP anomalies based on the autumn ENSO state. *Journal of Climate*.
Rayner NA, Horton EB, Parker DE, Folland CK, Hackett RB. 1996. Version 2.2 of the global sea-ice and sea surface temperature data set, 1903–1994, CRTN 74. Hadley Centre, Met Office, Bracknell, UK.
Rocha A. 1999. Low-frequency variability of seasonal rainfall over the Iberian Peninsula. *International Journal of Climatology* **19**: 889–901.
Rodó X, Baert E, Comín F. 1997. Variations in the seasonal rainfall in southern Europe during the present century: relationship with the North Atlantic oscillation and the El Niño–Southern Oscillation. *Climate Dynamics* **13**: 275–284.
Rodwell MJ, Folland CK. 2002. Atlantic air–sea interaction and seasonal predictability. *Quarterly Journal of the Royal Meteorological Society* **128**: 1413–1443.
Serrano A, Garcia AJ, Mateos VL, Cancillo ML, Garrido J. 1999. Monthly modes of variation of precipitation over the Iberian Peninsula. *Journal of Climate* **12**: 2894–2919.
Trenberth KE. 1997a. Short-term climate variations: recent accomplishments and issues for future progress. *Bulletin of the American Meteorological Society* **78**: 1081–1096.
Trenberth KE. 1997b. The definition of El Niño. *Bulletin of the American Meteorological Society* **78**: 2771–2777.
Trenberth KE, Hurrell JW. 1994. Decadal atmosphere–ocean variations in the Pacific. *Climate Dynamics* **9**: 303–319.
Trenberth KE, Branstator GW, Karoly D, Kumar A, Lau N, Ropelewski C. 1998. Progress during TOGA in understanding and modelling global teleconnections associated with tropical sea surface temperatures. *Journal of Geophysical Research* **103**: 14 291–14 324.
Trigo RM, Pozo-Vázquez AD, Osborn T, Castro-Díez Y, Gámiz-Fortis SR, Esteban-Parra MJ. 2004. North Atlantic Oscillation influence on precipitation, riverflow and water resources in the Iberian Peninsula. *International Journal of Climatology* **24**: 925–944.
Van Loon H, Madden RA. 1981. The Southern Oscillation. Part I: global associations with pressure and temperature in the northern winter. *Monthly Weather Review* **104**: 1354–1361.
Van Oldenborgh GJ, Burgers G, Tank AK. 2000. On the El Niño teleconnection to spring precipitation in Europe. *International Journal of Climatology* **20**: 565–574.
Wilby RL. 1993. Evidence of ENSO in the synoptic climate of the British Isles since 1880. *Weather* **48**: 234–239.

