# The Association between ENSO and Winter Atmospheric Circulation and Temperature in the North Atlantic Region

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ABSTRACT

The association among ENSO, the Northern Hemisphere sea level pressure (SLP), and temperatures in Europe has been analyzed during the period 1873–1995. In the first part, the SST of the Niño-3 region has been used to select extreme cold and warm ENSO events and periods that can be regarded as normal. The study was carried out for winter with the constraints that the ENSO events were well developed during the winter of study, and that they are extreme events. Composites of winter SLP and temperatures have been made for the selected cold and warm events as well as for normal cases and compared with each other. In the North Atlantic area, no statistically significant SLP anomaly patterns were found associated with warm events, while during cold events a statistically significant anomaly pattern resembling the positive phase of the North Atlantic oscillation (NAO) was found. The temperature analysis shows statistically significant negative anomalies during cold events over the Iberian Peninsula and positive anomalies over the British Isles and southern Scandinavia, consistent with the SLP anomalies. The SLP and temperatures have also been analyzed for spring. The patterns resemble those found for winter but the anomalies have lower amplitudes. For the completion of the composite analysis, the consistency among events of the relationship between ENSO and SLP as well as between ENSO and temperatures was examined. The results show that the significant patterns found in the composite analysis in the North Atlantic area are not the result of a few major events, but rather because both the SLP and temperature anomalies in this area during cold ENSO events are stable and qualitatively similar to those found during the positive phase of the NAO. The possible physical basis for this association between NAO and ENSO is discussed.

## 1. Introduction

The El Niño–Southern Oscillation (ENSO) phenomenon is recognized as a major source for global climate variability. Numerous studies, especially during the last years, have dealt both with the underlying physics of the phenomenon and with the worldwide implications for climate (van Loon and Madden 1981; Kiladis and Diaz 1989; Ropelewski and Halpert 1989; Halpert and Ropelewski 1992; Trenberth et al. 1998). The association between ENSO and climate anomalies in the tropical Pacific region is well documented. On the other hand, the impact of ENSO on the climate of the extratropical regions, as well as the mechanism responsible for anomalies in the tropical Pacific SST having worldwide impacts, are not so well documented.

Particularly, the impact of ENSO on the climate of the North Atlantic region is still largely unknown. Few works have dealt with this problem; some of them show circulation changes in the North Atlantic associated with the ENSO (van Loon and Madden 1981; Fraedrich 1990, 1994; Fraedrich et al. 1992). The impact of ENSO on circulation in the North Atlantic region has been examined by some authors through the study of the association between the North Atlantic oscillation (NAO) and the ENSO (Rogers 1984; Huang et al. 1998). Ev-

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idence of the impact of ENSO on temperatures and precipitation in Europe has also been reported (Kiladis and Diaz 1989; Halpert and Ropelewski 1992; Fraedrich and Müller, 1992; Wilby 1993; Rodó et al. 1997).

Two recent studies, by Dong et al. (2000) and Grötzner et al. (2000), provide observational data and model results indicating an influence of the last two ENSO events, El Niño 1997/98 and La Niña 1998, on the climate of the North Atlantic region.

These studies on the implications of ENSO for the climate of the North Atlantic shows varied results and, in some cases, even contradictory results. As commented by Trenberth (1997a), the research challenges in the understanding of ENSO teleconnections in higher latitudes are many, and much work is needed. Particularly, according to Trenberth (1997a) ''continued efforts should be made to improve the existent observational database and analyse the dataset of known quality.'' The aim of the present study is to increase current knowledge concerning the association between European climate and ENSO during the period 1873–1995. Our strategy is based on the study of the climate 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 analyze these climate anomalies, the consistency among events, and also their statistical significance.

The possible relationship between European climate and ENSO can have important implications for seasonal forecast of European climate and GCM validation. Particularly, 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 6–12 months (see Latif et al. 1998 for a thorough review of the state of the art of ENSO predictability).

The present study is structured as follows. In section 2, we discuss the criteria for the selection of the warm and cold ENSO events. We also describe in this section the data used in the paper. In section 3, we make composites of winter and spring Northern Hemisphere sea level pressure (SLP) and European temperatures for the selected ENSO events. We also investigate the consistency among events of the relationship among ENSO, SLP, and temperatures. In section 4, we conclude with a summary and discussion.

## 2. Methodology and data

The search for ENSO signals in the North Atlantic area presents several difficulties. First, 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. Second, climatological planetary atmospheric waves, natural noise, and the complexity of the numerous feedbacks (and maybe nonlinear relationships) can hide the signal of ENSO in the extratropics (Trenberth 1997a). Many authors have argued that only when tropical SST anomalies are large can the ENSO signal be found in the extratropics (Trenberth et al. 1998; Huang et al. 1998). On the other hand, tropical forcing is stronger during the northern winter, coinciding with the mature stage of El Niño events (Trenberth et al. 1998). Besides this, the greatest strength of the circulation in the North Atlantic area is found during winter (Moses et al. 1987). Thus, it appears that the possible influence of ENSO in the North Atlantic regions is more likely to be found during extreme events of ENSO and during the winter.

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 1) are considered extreme and 2) can influence the North Atlantic area during winter.

There is no general agreement on the definition of the ENSO or on which indicator (pressure indices or SST indices) should be used (Trenberth 1997b). In this work, we have used the Niño-3 SST region (5°S–5°N, 90°–150°W) to monitor the ENSO. SST data for the period 1871–1995, from the Met Office Global Sea-Ice and SST data (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. The selection of this reference period avoids the use of the 1980s, with the strong warm ENSO events during this decade that can bias the reference period. Finally, seasonal values are calculated by averaging the corresponding monthly values: December–February (DJF) for winter and September–November (SON) for autumn.

Extreme ENSO events have been selected based on the analysis of these seasonal SST normalized series. For El Niño events, we selected those years in which current winter and the preceding autumn have an index value roughly equal to or greater than one standard deviation. For La Niña events, we used similar criteria for those years in which the preceding autumn and the current winter have an index value roughly equal to or less than minus one standard deviation. The criteria for preceding autumn ensures that during the winter, the ENSO events will be well developed, having had time eventually to affect the North Atlantic area. Figure 1 shows the time series of the Niño-3 normalized SST indices for both winter and the preceding autumn. Since our

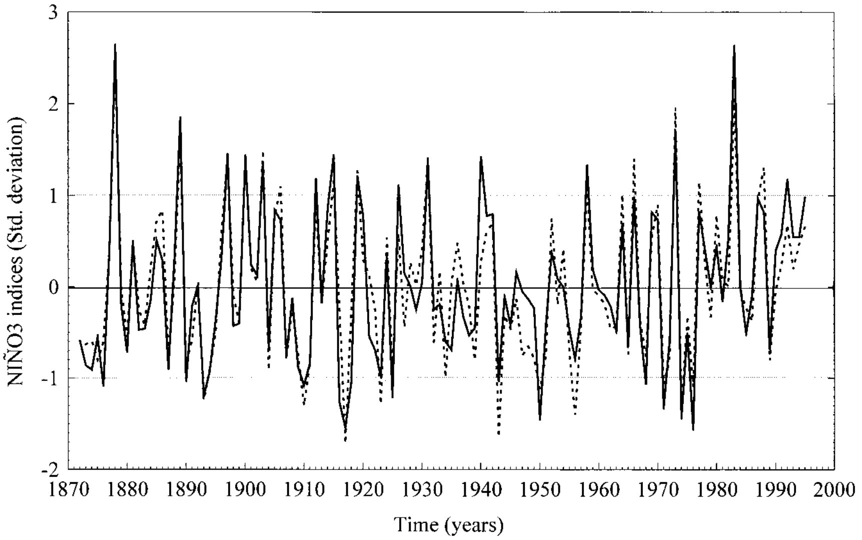


FIG. 1. Time series plots of the Niño-3 normalized SST indices. The continuous line in the index for winter and the dotted line refers to the index of the preceding autumn. Indices are seasonally averaged based on monthly normalized to the period 1951–80. The lines corresponding to one standard deviation are also shown.

purpose is to study an eventual climatic signal of ENSO in Europe, we must be able to compare the situation during extreme ENSO events with periods that can be regarded as normal. These periods are not necessarily all the years selected as extreme events. Some ENSO episodes may fulfill one of the criteria, the criterion for winter or the criterion for the preceding autumn. 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 to be those that fulfill neither of the two criteria. We will refer to these hereafter as ''normal'' years. Table 1 lists the selected cases. There are 18 El Niño and 13 La Niña cases and 67 normal cases in the period 1873–1995. The selected warm and cold events agree with those proposed by several authors (Trenberth 1997b; van Loon and Madden 1981; Halpert and Ropelewski 1992; Hoerling et al. 1997). Included in this list of normal years are some episodes considered in the bibliography as moderate El Niño and La Niña events, and even strong events, but do not satisfy the criteria we have used to select warm and cold events.

TABLE 1. List of El Niño, La Niña, and normal event years used in the composite analysis. The indicated event year refers to the winter (Dec–Feb) season, taken as the year of Jan and Feb. The period of analysis is 1873–1995.

| El Niño | La Niña | Normal | | | |
|---|---|---|---|---|---|
| 1878 | 1890 | 1875 | 1908 | 1946 | 1975 |
| 1889 | 1893 | 1877 | 1913 | 1947 | 1978 |
| 1897 | 1894 | 1879 | 1921 | 1948 | 1979 |
| 1900 | 1910 | 1880 | 1922 | 1949 | 1981 |
| 1903 | 1911 | 1881 | 1924 | 1951 | 1982 |
| 1906 | 1917 | 1882 | 1927 | 1952 | 1984 |
| 1912 | 1923 | 1883 | 1928 | 1953 | 1985 |
| 1915 | 1925 | 1884 | 1929 | 1954 | 1986 |
| 1919 | 1943 | 1885 | 1930 | 1955 | 1989 |
| 1931 | 1950 | 1888 | 1932 | 1957 | 1990 |
| 1958 | 1971 | 1891 | 1933 | 1959 | 1991 |
| 1966 | 1974 | 1892 | 1935 | 1960 | 1993 |
| 1970 | 1976 | 1895 | 1936 | 1961 | 1994 |
| 1973 | | 1896 | 1937 | 1962 | |
| 1977 | | 1898 | 1938 | 1963 | |
| 1983 | | 1899 | 1939 | 1965 | |
| 1987 | | 1901 | 1944 | 1967 | |
| 1988 | | 1902 | 1945 | 1972 | |

The monthly mean SLP for the region 15°–85°N has been analyzed. The data are on a 5° latitude by 10° longitude grid basis, covering the period 1873–1995, and have been provided by the Climatic Research Unit at the University of East Anglia, United Kingdom. The sources of the original chart data are given in Jones (1987). The mean for the period 1951–80 has been subtracted from the monthly data and seasonal averages for winter and spring (Mar–May) that were determined by averaging the corresponding monthly anomaly values.

Gridded winter air temperature data from 1873 to 1995 of the North Atlantic land regions, has also been analyzed. The data are defined on a 5° latitude by 5° longitude gridbox basis and are expressed as anomalies from the monthly means of the period 1951–80, (Jones 1994; Jones et al. 1999). Winter and spring seasonal averages were determined by averaging the corresponding monthly anomaly values.

With this database, composites of the Northern Hemisphere SLP and temperatures of Europe during winter were made based on the selected ENSO events. The 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 99% level for a two-tailed test of the null hypothesis of no difference of means. The test was applied both to compare the composites of SLP and temperature 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. When a particular value was missing from a grid, the data were not included in the composite.

Finally, for completion of the composite analysis, we have examined the consistency among events in the relationship between ENSO and SLP as well as between ENSO and temperatures. 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 following Kiladis and Diaz (1989), whose method consists of calculating the percentage of consistent signals, which is defined as the percentage of events having anomalies with the same sign as that of the composite anomaly.

We have also studied the SLP and temperatures during the spring following the winter of ENSO events. Most ENSO events begin between March and September and end between February and March (Trenberth 1997b), with the peak of the anomalies during the northern winter. Given the lag of around 3 months between the setting of an ENSO event and an eventual propagation to the extratropics, it seems reasonable to expect certain ENSO signals during the spring following a winter with an extreme ENSO event. We do not require the ENSO event to still be taking place during the spring, so this study gives certain forecasting information concerning the spring following an ENSO event during winter.

The values of the NAO index were also analyzed based upon the ENSO state. A seasonal index representative of the NAO was used to monitor the NAO during the period 1873–1995. The index was formulated using pressure data from the Azores and Iceland (Jones et al. 1987, 1997). Normalization relative to the period 1951–80 was used. The way in which the index was formulated, the rationale in using this particular index, and their main characteristics are thoroughly discussed in Pozo-Vázquez et al. (2000a).

## 3. Analysis and discussion

### *a. Observed patterns during winter*

#### 1) SEA LEVEL PRESSURE

Composites of SLP anomalies during winter were made based on the selected cases (Table 1). Figure 2a shows the composite of SLP anomalies for the selected El Niño events, Fig. 2b for normal cases, and Fig. 2d for La Niña cases. A negative anomaly pattern is centered south of the Aleutian Islands during El Niño cases (Fig. 2a). This center reaches negative anomalies of −3 mb. During La Niña (Fig. 2d), positive anomalies are found southwest of the Aleutian Islands. Both patterns are statistically significant when they are compared with the normal situation (Figs. 2c and 2e). These patterns are consistent with a deepening of the Aleutian low pressure center during El Niño events and a weakening during La Niña. The amplitude of the anomalies is of the same order in both La Niña and El Niño events. The same behavior was found by Hoerling et al. (1997). Over the southeastern part of the United States, weak (but statistically significant) anomalies can be found when comparing El Niño and normal years (Fig. 2c). No statistically significant signature was found over the North Atlantic region.

During La Niña (Fig. 2d) a relatively strong anomaly pressure pattern is also found over the North Atlantic area. There is an anomalous high pressure band over the central Atlantic (over Azores) and an anomalous low pressure over the area south of Iceland. The comparison of this pattern with those of normal years, shows that both areas are statistically significant (Fig. 2e). Particularly, the significance area extends from the Azores to the Florida peninsula. This SLP anomaly pattern closely resembles the positive phase of the NAO, with an intensification of the Azores high and a deepening of the Icelandic low.

We considered the association between the NAO and the ENSO phenomena through the analyses of the NAO index during the ENSO events. Table 2 shows a composite of the values of the NAO index from the autumn of the onset of the ENSO events to the following spring. The composite was calculated over El Niño, La Niña, and normal years. For La Niña years, the mean value of the NAO index in winter was 0.98, while for El Niño 0.47, and for normal 0.22. The difference between the composite value for La Niña and normal years is statistically significant at the 98.5% confidence level using a $t$ test ($p$ value 0.015). During the spring, the value of the NAO index for La Niña is still slightly greater than for normal springs, 0.32 versus −0.05, and still statistically significant at the 90% confidence level ($p$ value 0.081). Thus, it can be concluded that for extreme La Niña events, higher than average climatological values of the NAO index can be expected during winter and the following spring, with the subsequent consequences for the North Atlantic area climate.

Figure 2f shows the difference between El Niño and La Niña. Statistically significant areas are, fundamentally, those found in Fig. 2e, but over a greater area. Slightly higher pressures can also be expected over central Europe during La Niña than during El Niño. This result was also found by Fraedrich (1990).

#### 2) TEMPERATURE

As in the case of SLP, composites of temperature anomalies in Europe during winter were made based on

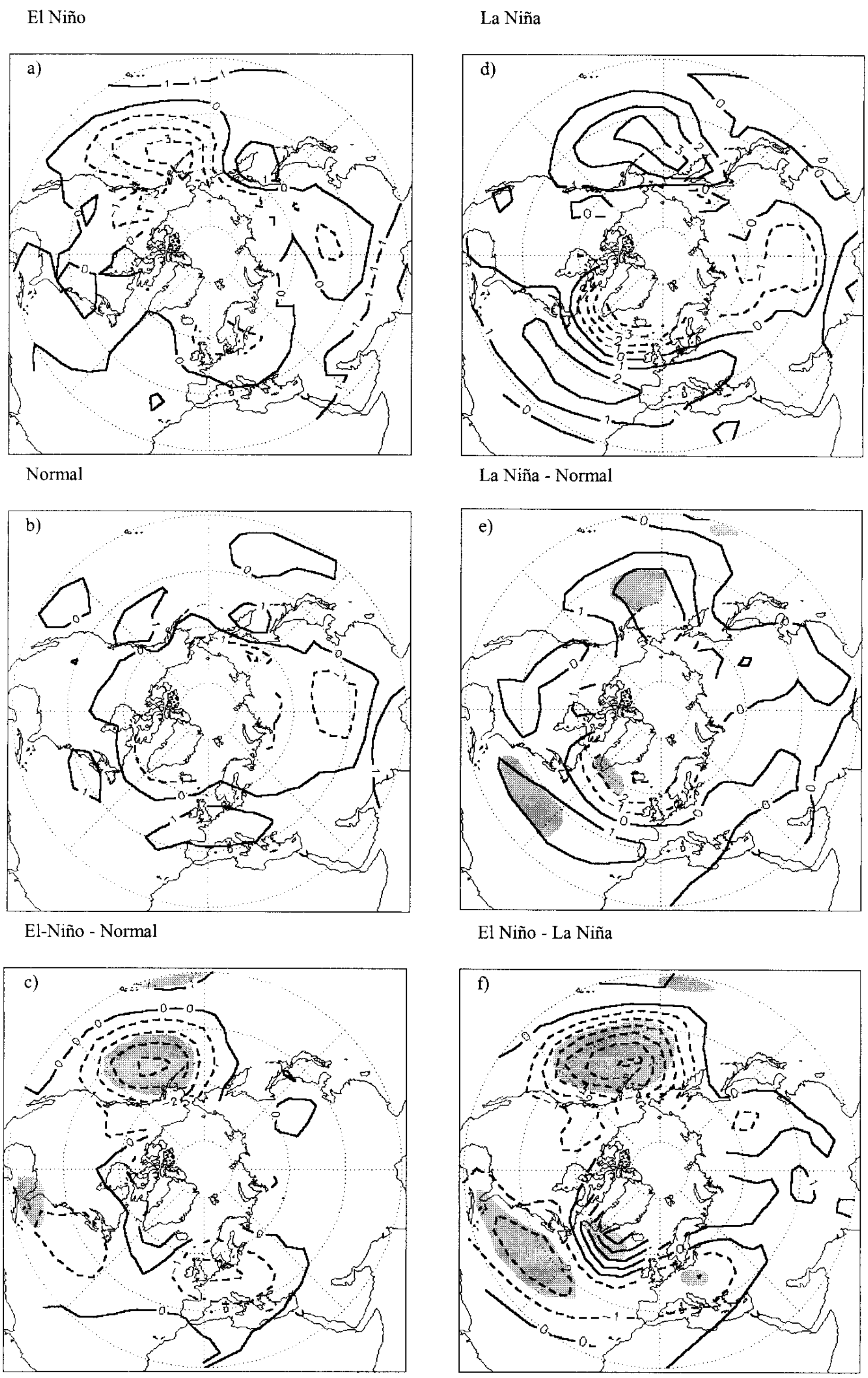


FIG. 2. Composites of winter (DJF) observed SLP anomalies. See Table 1 for the years included in the composites. (a) During El Niño, (b) during normal winters, and (c) difference, (a) minus (b). (d) Anomalies during La Niña and (e) difference, (d) minus (b). (f) Difference between El Niño and La Niña, (a) minus (d). Contour interval is 1 mb. Continuous line indicates positive or zero anomalies and dotted line indicates negative anomalies. Shading indicates local statistical significance of the difference at 99% confidence level, based on a *t* test.

TABLE 2. Composite NAO index associated with El Niño, La Niña, and normal years. The index value is shown for the autumn of the ENSO onset year and for the following winter and spring.

| | Autumn | Winter | Spring |
|---|---|---|---|
| El Niño | −0.44 | 0.47 | 0.00 |
| La Niña | −0.11 | 0.98 | 0.32 |
| Normal | −0.06 | 0.22 | −0.05 |

the selected ENSO events. Figure 3a shows the composite during El Niño events, Fig. 3b for normal years, and Fig. 3c shows the differences, Fig. 3a minus Fig. 3b, between the two patterns. During El Niño years, maximum positive anomalies in winter, of the value 0.25°C, are found over central Europe and the southernmost part of the Iberian Peninsula. In winter of normal years, negative anomalies of the value −0.25°C are found over the Iberian Peninsula and up to −0.5°C over the southern of the Italian peninsula (Fig. 3b). Statistically nonsignificant differences were found between El Niño and normal winter (Fig. 3c).

Figure 3d shows the composite of temperature anomalies for winter during La Niña events and Fig. 3e shows the differences of Fig. 3d minus Fig. 3b. During La Niña winters, positive temperature anomalies of values between 0.5° and 1°C are found over northern Germany, Poland, southern Scandinavia, and the British Isles. On the other hand, negative anomalies are found over southwest France, the southern part of the Italian peninsula, and the Iberian Peninsula. The Iberian peninsula shows minimum negative anomalies, reaching −1°C. Very similar results were reported by Fraedrich and Müller (1992). Differences between La Niña and normal winters are statistically significant over the center and south of the Iberian Peninsula, registering values of up to −0.5°C (Fig. 3e). Over northern Britain and southern Scandinavia, differences are also statistically significant but positive, with values between 0.5° and 1°C.

We also analyzed the differences between El Niño and La Niña winters. Figure 3f shows the differences between Fig. 3a and Fig. 3d. Differences are statistically significant and positive (around 0.75°C) over the central and southwestern part of the Iberian Peninsula, and statistically significant and negative over northern Britain (reaching values of −0.5°C) as well as southern Scandinavia (reaching values of −1°C).

The temperature anomalies found in Fig. 3 agree with the changes in the circulation reflected in Fig. 2. Particularly, during La Niña winters, a statistically significant pattern of SLP anomalies, resembling the positive phase of the NAO, appears over the North Atlantic region. The temperature anomalies found for La Niña events are consistent with the results that can be expected for this state of the NAO (Hurrell 1995; Hurrell and van Loon 1997; Osborn et al. 1999; Pozo-Vazquez et al. 2001).

### b. *Observed patterns during spring*

We have studied the SLP and temperatures during the spring following the winter of ENSO events. Since we do not taken into account the state of ENSO in spring, this study gives certain forecasting information concerning the climate during the spring following an extreme winter ENSO event.

#### 1) SEA LEVEL PRESSURE

The composite of SLP anomalies for El Niño (Fig. 4a), normal cases (Fig. 4b), and the differences together with a *t* test of significance (Fig. 4c) are shown. Figure 4a shows that the deepening of the low pressure center over the Aleutian Islands, characteristic of El Niño during winter, is still visible during the following spring, although weaker. The very center of the anomaly pattern is statistically significant when compared with normal years (Fig. 4c). Areas of statistical significance appear over the southeastern United States. No statistically significant signature is detected over the North Atlantic region. During La Niña years (Fig. 4d) the anomaly pattern south of the Aleutian Islands disappears, and statistically nonsignificant differences are found between the pressure in this area during La Niña and normal cases (Fig. 4e). On the other hand, over the North Atlantic region an anomaly pattern is detected. As for winter, the pattern resembles the positive phase of the NAO, but anomalies are lower than in that case and displaced northward (as might be expected by the migration of the semipermanent pressure center during spring and summer). Only the center of the high pressure anomalies, north of the Azores Islands, is statistically significant when compared with normal years. The composite of the NAO index for spring during La Niña cases is 0.32 and −0.05 during normal cases, the difference being statistically significant [see section 3a(1)]. In Figure 4f, showing the difference between El Niño and La Niña years, a notable band of statistical significance appears over the central Atlantic and over the west coast of California.

#### 2) TEMPERATURE

The composites of temperature anomalies during El Niño (Fig. 5a), during normal years (Fig. 5b), and the differences (Fig. 5c) were also computed. Statistically nonsignificant areas are found when comparing patterns in Figs. 5a and 5b, as can be expected from the pressure anomaly pattern. In Fig. 5d, showing the anomalies during La Niña cases, the pattern resembles those found for winter, but the anomalies have lower values for most of the area analyzed. Anomalies of up to −1°C are found over the Iberian Peninsula. The comparison of values in Figs. 5b and 5d shows that only the western Iberian Peninsula and northern Algeria have values with statistically significant differences during La Niña and normal

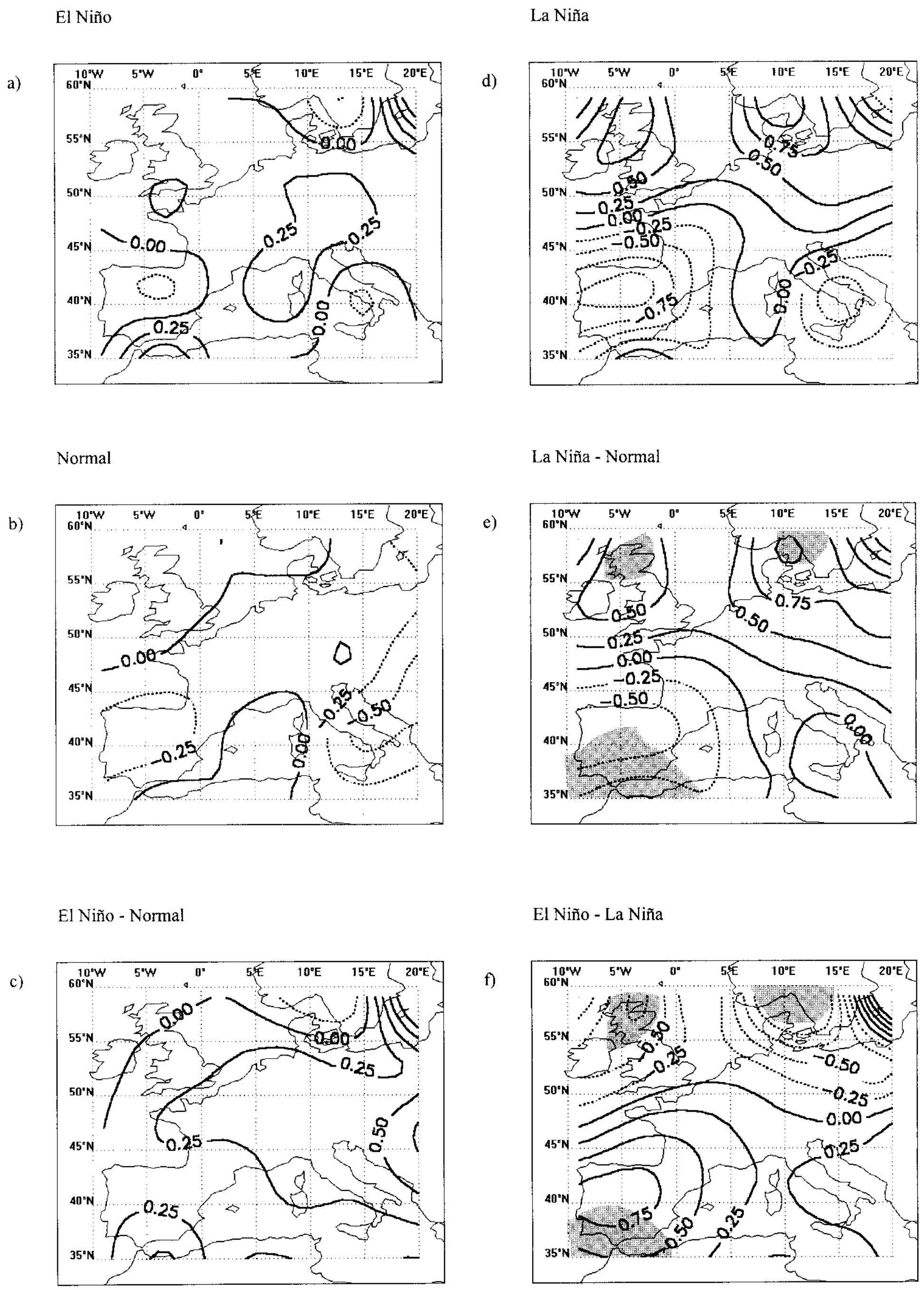


FIG. 3. As in Fig. 2 but for the observed temperatures in Europe. Contour interval is 0.25°C. Continuous line indicates positive or zero anomalies and dotted line indicates negative anomalies. Shading indicates local statistical significance of the difference at 99% confidence level, based on a *t* test.

years (Fig. 5e). These temperature anomalies are difficult to explain based only on the changes in the circulation reflected in Fig. 4. When comparing El Niño and La Niña cases (Fig. 5f), only the very western edge of the Iberian Peninsula shows different behavior (statistically significant).

### *c. Stability of the patterns*

#### 1) Consistency of the SLP patterns

We studied the consistency among events in the relationship between ENSO and SLP by calculating the percentage of consistent signals. Figures 6a and 6b

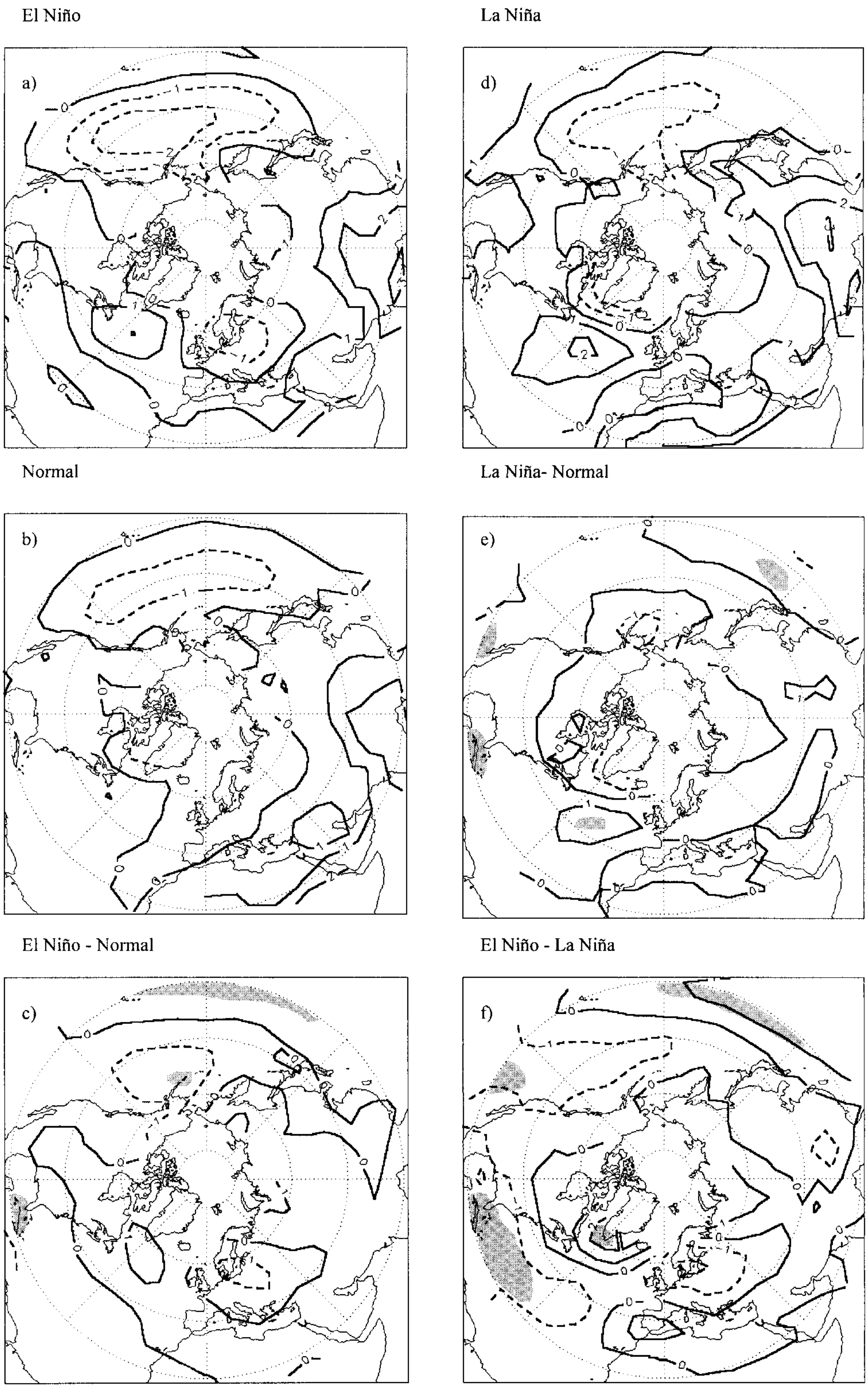


FIG. 4. As in Fig. 2 but for the spring following the winter of the ENSO event.

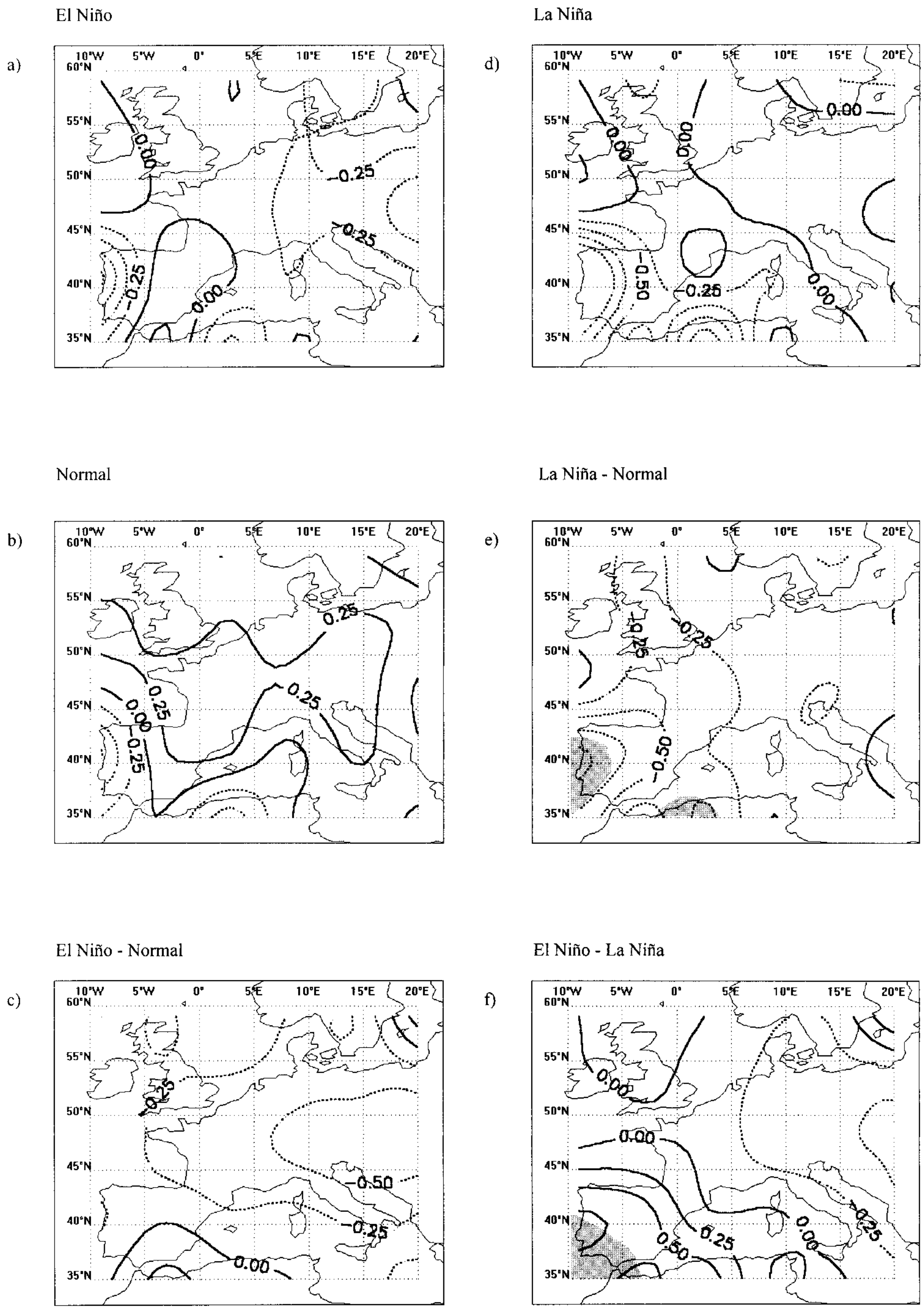


FIG. 5. As in Fig. 3 but for the spring following the winter of the ENSO event.

show, respectively, the results for El Niño and La Niña during winter, while Figs. 6c and 6d show the results for El Niño and La Niña during spring.

During winter, the ENSO signal over the Aleutian Islands appears to be more stable during La Niña (with 90% coherence) than during El Niño (70%). Furthermore, the area with high coherence is larger during La Niña than during El Niño. It is known that these anomaly patterns are not always present during ENSO events. Our analysis suggests that during extreme events, these

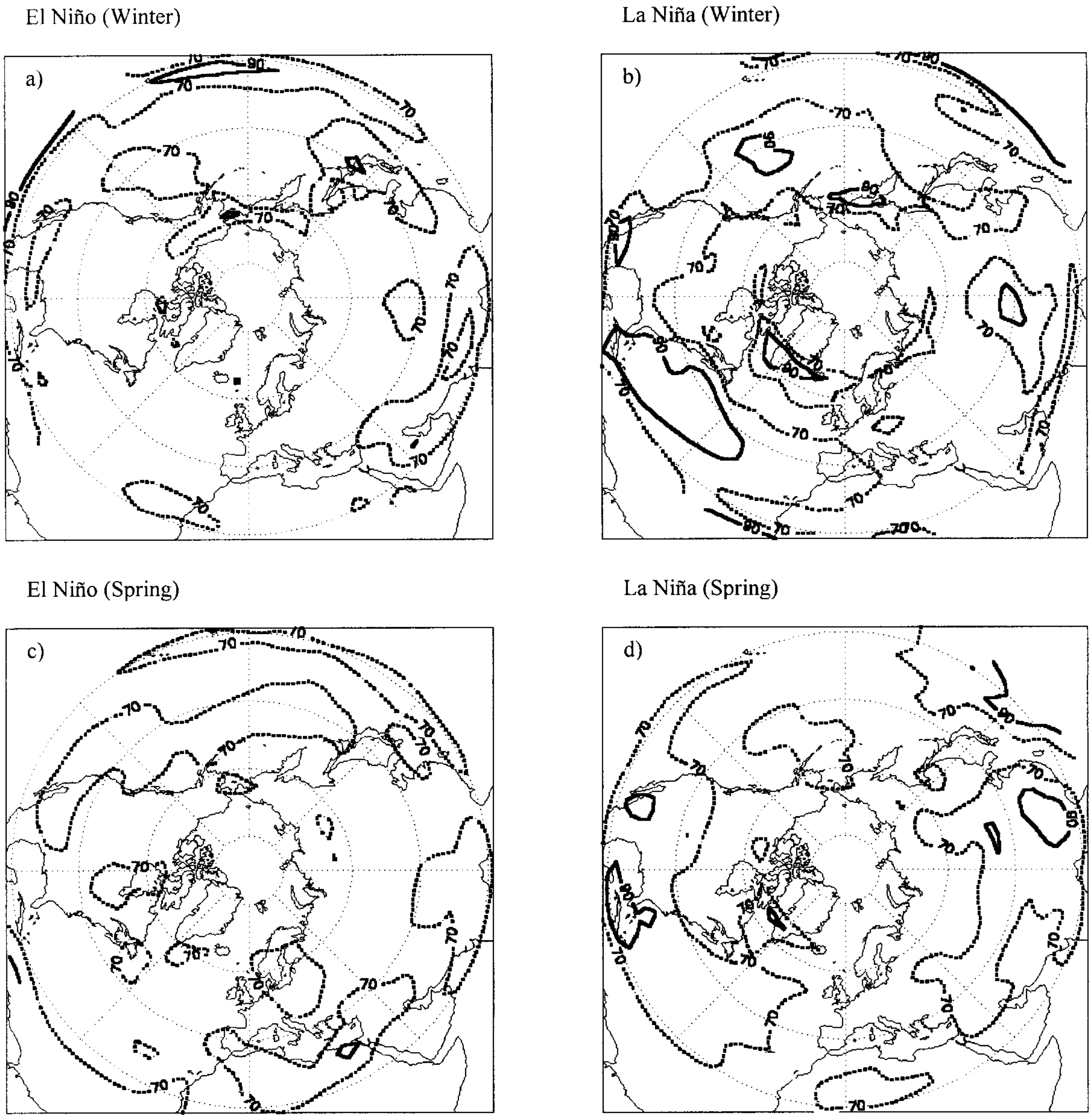


FIG. 6. Study of the consistency among events of the relationship between the ENSO and SLP anomalies. (a) The percentage of events having anomalies with a sign consistent with the composite anomaly for El Niño and during the winter. (b) As (a) but for La Niña. (c) and (d) As, respectively, (a) and (b) but for the spring following an extreme ENSO event during the winter. Dotted line indicates 70% and continuous line indicates 90%.

patterns are very likely to be found. Over the south of the peninsula of Baja California, coherence reaches 90% during La Niña. Strong coherence also appears over the North Atlantic area during La Niña, with 90% coherence in the central Atlantic and over Iceland (roughly over the dipole centers of the NAO). No significant coherence is evident over this area during El Niño. This indicates that the SLP anomaly patterns over the North Atlantic area in Figs. 2d and 2e are not the result from a few major events, but rather because the SLP anomaly in this area during cold ENSO events is quite stable and qualitatively similar to those found during the positive phase of the NAO.

During the spring following an extreme ENSO event in winter the percentage of coherence is lower than during winter, but in some areas it still greater than 70%. Particularly, over the Aleutian Islands, the percentage reaches 70% both during warm and cold ENSO events. In the North Atlantic area, the percentage is 70% over the central Atlantic and reaches 90% over Greenland. In the southern part of Florida 90% coherence can also be found.

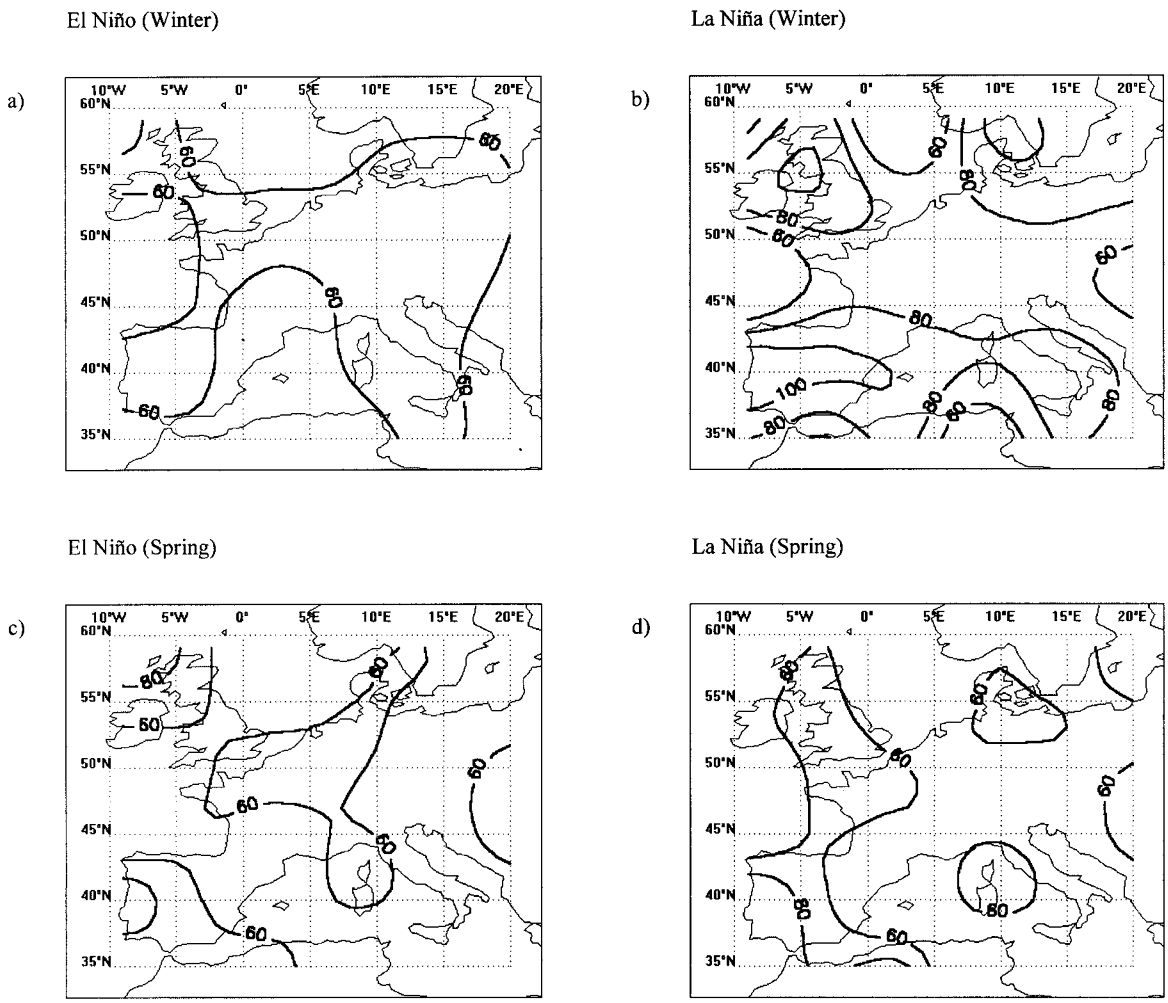


FIG. 7. Study of the consistency among events of the relationship between the ENSO and temperature anomalies. (a) The percentage of events having anomalies with a sign consistent with the composite anomaly for El Niño and during the winter. (b) As (a) but for La Niña. (c) and (d) As, respectively, (a) and (b) but for the spring following an extreme ENSO event during the winter. Contour interval is 20%, ranging from 60% to 100%.

#### 2) CONSISTENCY OF THE TEMPERATURE PATTERNS

We have also studied the consistency among events in the relationship between ENSO and temperatures. Figures 7a and 7b show, respectively, the results for El Niño and La Niña during winter, and Figs. 7c and 7d show the results for El Niño and La Niña during spring. The greatest consistency appears for La Niña during winter (Fig. 7b). Values between 80% and 100% are registered over the Iberian Peninsula, the British Isles, southern Scandinavia, northern Germany, and Poland, the areas complements those found in section 3a(2) using the *t* test and agrees with the results of the SLP analysis, showing that the temperature anomalies in the former regions of Europe are not the results of statistical sampling or a few La Niña events, but rather are associated with a cold ENSO event signature in the climate of Europe. On the other hand, during El Niño events (Fig. 7a) no coherence is found. This means that the positive composite temperature anomalies detected over central Europe during El Niño events (Fig. 3a) do not constitute a stable signal, but rather that this value is due to sampling and/or to a few anomalies associated with some particular El Niño events. As in the La Niña events, this result confirms the results of the *t* test in section 3a(2) and agrees with the results of the SLP analysis.

During spring and for El Niño events (Fig. 7c) no coherence appears, as might be expected based on the *t*-test analysis of the temperatures (Fig. 5c). For La Niña events (Fig. 7d) and over the southwestern part of the Iberian Peninsula, coherence around 80% is found, confirming the results of the *t* test in Fig. 5e.

## 4. Concluding remarks

### *a. Summary*

The association between the ENSO and SLP and temperatures in Europe has been analyzed during the period

1873–1995. The study is carried out for winter and with the constraint that the ENSO events were well developed during the winter of study. Composites of winter Northern Hemisphere SLP and European temperatures were obtained for the selected cold and warm ENSO events and compared with the composites made for normal years.

In the North Atlantic area during winter and for La Niña events, we found a statistically significant SLP anomaly pattern resembling the positive phase of the NAO. No statistically significant patterns associated with El Niño events are found.

For the temperatures in Europe, statistically nonsignificant differences are detected between El Niño and normal winters. Differences between La Niña winters and normal winters are statistically significant and negative over the center and south of the Iberian Peninsula. Differences are also statistically significant but positive over northern Britain and southern Scandinavia. The temperature anomalies are consistent with the changes in the circulation resulting from the SLP analysis (the positive phase of the NAO).

The SLP and temperature anomalies were also analyzed for the spring following an ENSO event during winter. The analysis of the SLP during La Niña years shows, over the North Atlantic region, an anomaly pattern resembling the positive phase of the NAO, similar to that found for winter, but the anomalies are lower than in that case and northwardly displaced. The analysis of the European temperatures shows nonstatistically significant anomalies during the El Niño event. Differences between La Niña and normal events are statistically significant and negative over the western Iberian Peninsula.

The consistency analysis of the SLP and the temperatures shows that the significant patterns found in the composite analysis in the North Atlantic area are not the result of a few major events, but rather that both the SLP and temperature anomalies in this area during cold ENSO events are stable and qualitatively similar to those found during the positive phase of the NAO.

### b. Discussion

The composite and consistency analysis suggests an influence of the cold ENSO events on the atmospheric circulation of the North Atlantic region, particularly in the state of the NAO. Our results confirm those found by Dong et al. (2000) in the analysis of the influence of the La Niña 1998/99 events in the circulation of the North Atlantic region. Our results also agree with those of Fraedrich (1990), who reported that the European climate was influenced more strongly by cold than by warm ENSO events. The physical basis for this influences of the ENSO on the state of the NAO, and, particularly, for the more important influence of cold than warm ENSO events on the European climate, is difficult to assess.

Our analysis suggests that the PNA pattern may play an key role in the connection between the tropical forcing and the extratropical circulation response in the North Atlantic area, since the anomaly pattern in the Aleutian Islands was present in all the cold events analyzed. This anomaly pattern disturbs the mean flow and can trigger a standing wave train that propagates downstream to the North Atlantic area and, particularly, can give rise to the stable SLP anomaly pattern resembling the positive phase of the NAO found associated with the cold phase of ENSO. However, this simple Rossby wave–propagation paradigm does not explain why no signal is found in the North Atlantic area during the warm ENSO phase. The analysis of the SLP anomalies associated with individual El Niño events shows that the response of the SLP in the North Atlantic area to warm events greatly varies between events. One explanation for such a different response could be the different stability of the signal in the Aleutian Islands, which is more probable to be found during cold events (more than 90%) than during warm events (70% of the cases).

The tropical Atlantic SST could also act as a link between the tropical Pacific SST anomalies and the circulation of the North Atlantic region. In a recent work, Latif and Grötzner (2000) found an influence of the ENSO on the SST variability of the equatorial Atlantic, the equatorial Atlantic SST lagging by about 6 months. Saravan and Chang (2000) and Li (2000) have also described an influence of the ENSO on the tropical Atlantic. Additionally, several studies, both using GCM experiments and observational records, suggested that changes in tropical Atlantic heating might affect Northern Atlantic circulation. Particularly, Watanabe and Kimoto (1999) found that tropical Atlantic SST anomalies seem to enhance the NAO selectively among other circulation patterns in the North Atlantic. Robertson et al. (2000) found an important influence of the tropical Atlantic SST anomalies on the NAO and proposed a mechanism to explain such influence. Also, Rajagopalan et al. (1998) found evidence for the influence of the tropical Atlantic SST on the NAO state.

It appears, therefore, that the response of the circulation in the North Atlantic region is some kind of mixture of tropical Atlantic forcing related to the tropical Pacific SST anomalies and the midlatitudes atmospheric forcing through the PNA teleconnection over North America. The difficulty in separating the influence from the tropical Pacific from those of the tropical Atlantic (Watanabe and Kimoto 1999; Dong et al. 2000) makes it difficult to assess which mechanisms are the most important in determining the state of the NAO.

Although our analysis suggests a stable influence of the cold phase of the ENSO on the NAO state, the judgment of the possible significance of this influence and its physical basis, founded just on the observational record analyzed, is difficult and must wait further analyses with GCMs and other observational record.

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