

## Euro-Mediterranean rainfall and ENSO—a seasonally varying relationship

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[1] Using observational datasets and atmospheric reanalyses, we show that interannual variability of rainfall in the Euro-Mediterranean sector is significantly influenced by ENSO in a way that is seasonally varying. Spatially coherent correlation patterns are found in central and eastern Europe during winter and spring, and in western Europe and the Mediterranean region during autumn and spring. A composite analysis of ENSO events indicates that during an El Niño western Mediterranean rainfall has a 10% increase (decrease) in the autumn preceding (spring after) the mature phase of an event, corresponding to a rainy season arriving (retreating) earlier compared to the climatology. The atmospheric reanalyses show that an anomalous atmospheric circulation and moisture transport extending from the Atlantic Ocean into the Euro-Mediterranean region accompanies the observed rainfall anomalies. Multidecadal variations characterize the ENSO Euro-Mediterranean relationship during the 20th century. *INDEX TERMS:* 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504); 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854); 4215 Oceanography: General: Climate and interannual variability (3309); 9335 Information Related to Geographic Region: Europe

### 1. Introduction

[2] It has long been a matter of debate whether and how the El Niño Southern Oscillation (ENSO) warm and cold extremes influence Euro-Mediterranean rainfall. An early study by *Ropelewski and Halpert* [1987], observed some anomalous rainfall occurring in southern Europe and Mediterranean Middle East regions, but concluded that the influence of ENSO in these regions was indeterminate. *Kiladis and Diaz* [1989] found that some areas in central Europe and the Mediterranean region experience anomalous rainfall at particular stages of the ENSO cycle. Later works, focusing directly on the European region, pointed to significant rainfall anomalies mostly

during winter and spring [*Fraedrich and Muller*, 1992; *Moron and Ward*, 1998; *van Oldenborgh et al.*, 2000]. A number of other papers have indicated that ENSO related rainfall anomalies are found at a nation-wide scale in Mediterranean and Middle East regions also in other periods of the year [*Rodo et al.*, 1997; *Price et al.*, 1998; *Turkes*, 1998; *Arpe et al.*, 2000; *Nazemosadat and Cordery*, 2000].

[3] This paper aims to contribute to an improved definition of the relation between ENSO and the interannual variability of rainfall in the Euro-Mediterranean sector, evidencing, in particular, spatially coherent correlation patterns and their seasonal variations.

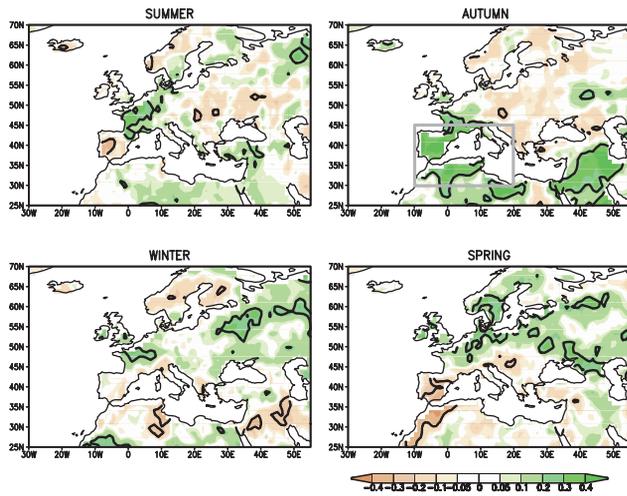
### 2. Data

[4] We consider 3-month means of rainfall from observational datasets and reanalyses: the land-only rain-gauge based gridded high resolution ( $0.5^\circ \times 0.5^\circ$ ) dataset of the CRU [*New et al.*, 2000] available from 1901–1996; the standard version of the CMAP gauge-satellite merged analyses [*Xie and Arkin*, 1996] for the period 1979–1997; the NCEP/NCAR reanalyses (NCEP hereafter; *Kalnay et al.*, 1996) from 1948–1998; the ECMWF reanalyses (ERA hereafter; *Gibson et al.*, 1997) for the period 1979–1993. NCEP reanalyses are also used to calculate 3-month mean vertically integrated moisture transport from 6-hrly data. Global sea surface temperatures (SST) are from the GISST dataset [*Rayner et al.*, 1997]; the Nino3.4 index is computed area-averaging SSTs in the region 190E–240E and 5S–5N.

[5] The interannual variations of rainfall in the Euro-Mediterranean sector, and in particular in the western Mediterranean region (10W–20E and 30–45N), are analyzed in relation to the SST anomalies by computing the correlation coefficients of 3-month mean variables; the level of significance is established by means of the Student-t test. Regression is used to study the relation between moisture flux anomalies and the variations of the Nino3.4 index.

[6] A number of major ENSO events, which occurred in the period 1948–1996, are selected to perform a composite analysis of rainfall anomalies (11 El Niño and 8 La Niña events). Following *Rasmusson and Carpenter* [1982], we define “year 0” as the one in which the Nino3.4 anomaly

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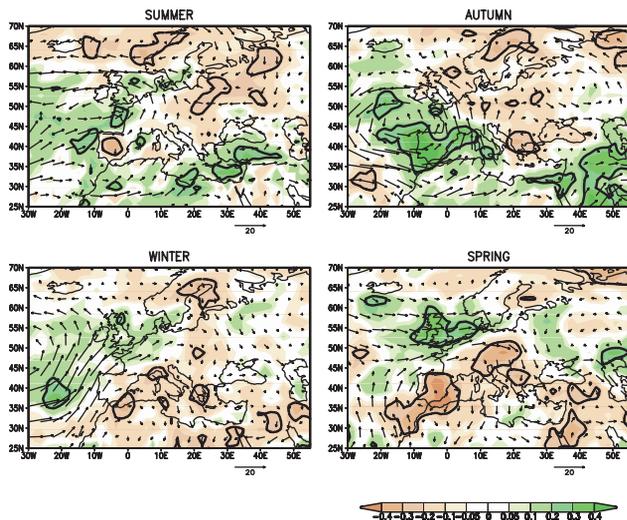


**Figure 1.** Seasonal correlation of rainfall in the Euro-Mediterranean region and the Nino3.4 index for the period 1948–1996. Rainfall data is from CRU. Correlation coefficients enclosed by contours are statistically significant at the 95% level. The grey box defines the region considered to compute western Mediterranean area-averages.

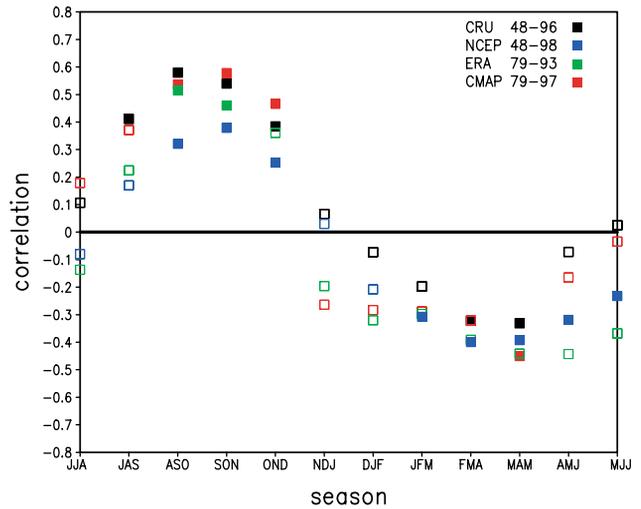
changes sign and the equatorial Pacific SST anomalies become strong, and “year + 1” as the year after.

### 3. Results

[7] Figure 1 presents the correlation between CRU rainfall in the Euro-Mediterranean region and the Nino3.4 index for the four standard seasons of the year. Spatially coherent patterns are found in central and eastern Europe where the correlation is negative in autumn and positive during winter

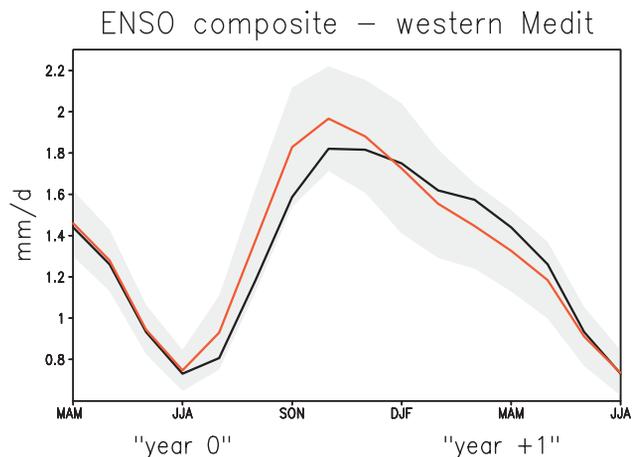


**Figure 2.** Seasonal regression of vertically integrated moisture flux and the Nino3.4 index (vectors). The seasonal correlation of rainfall with the Nino3.4 index is also reported (shaded; values enclosed by contours are statistically significant at the 95% level). Moisture flux and rainfall are derived from the NCEP reanalyses and are relative to the period 1948–98.

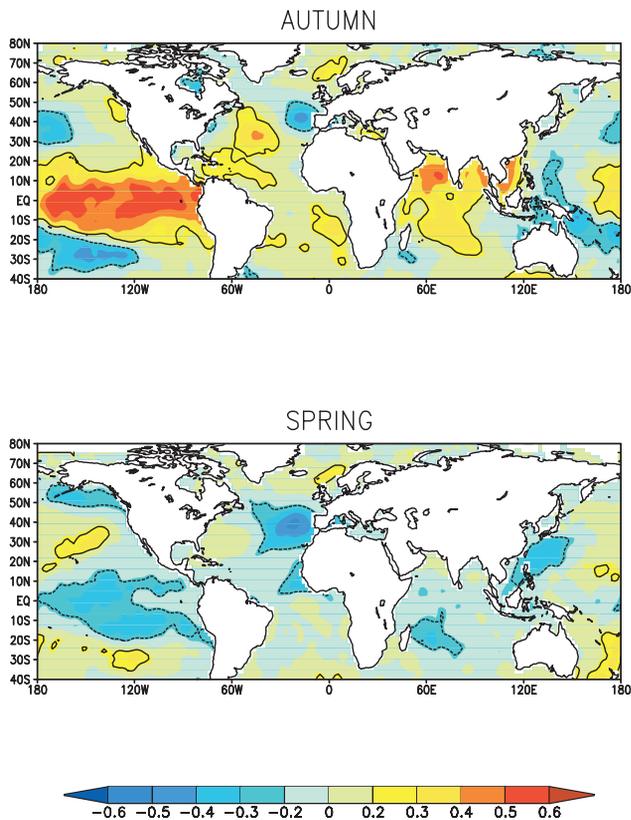


**Figure 3.** Correlation between western Mediterranean rainfall (various datasets) and the Nino3.4 index for 3-month means. The periods considered for each dataset differ according to availability and are specified in the legend; CRU is land-only. Full symbols are for values which are significant at the 95% level, empty symbols are for non-significant values.

and spring. In western Europe and the Mediterranean region the correlation is positive in autumn and negative in spring. The correlation coefficients derived using NCEP rainfall (Figure 2) are broadly consistent with those from CRU and show the above mentioned spatially coherent patterns also extending to the nearby Atlantic ocean and the Mediterranean sea. CMAP and ERA results have similar patterns (not shown; results are also consistent with the global analyses by *Dai and Wigley [2000]* and *Trenberth and Caron*



**Figure 4.** Composite of western Mediterranean seasonal rainfall (CRU, land-only) during selected ENSO events (red line) and climatology (black line); the gray shading depicts the rms of the ENSO events. The composite includes both El Nino and La Nina events (in this case the sign of the anomaly is reversed). Events begin (year 0) in: 1951, 57, 63, 65, 69, 72, 76, 82, 86, 91, 94 for El Nino and 1950, 54, 56, 64, 70, 73, 75, 88 for La Nina.



**Figure 5.** Correlation between western Mediterranean rainfall and global SST for autumn (SON) and spring (MAM). Rainfall is from CRU (land-only) while SST is from the GISST dataset; the correlation is relative to the period 1948–1996. Values enclosed by contours are statistically significant at the 95% level.

[2000]). The regression of NCEP data with Nino3.4 indicates a seasonally changing anomalous moisture flux in association with the observed rainfall anomalies (Figure 2): in autumn an anomalous cyclonic circulation brings enhanced moisture from the Atlantic to the western Mediterranean region; this flow turns north at about 20E, separating positive rainfall anomalies in the western Mediterranean and negative anomalies in the eastern Mediterranean. Anomalous moisture coming from the Arabian ocean brings more rain to Middle East regions toward the Caspian Sea. In winter and spring, a warm event causes anomalous moisture from the subtropical Atlantic to be channeled away from western Europe and toward higher latitudes where positive rainfall anomalies are found.

[8] The ENSO composite analysis of rainfall anomalies (both CRU and NCEP) in the Euro-Mediterranean region (not shown) is in agreement with the results of the correlation maps in Figures 1 and 2. The analysis further indicates that the autumn correlation is mostly due to the autumn season of the “year 0”, immediately before the mature phase of ENSO, while the winter and spring signals come mostly from the “year + 1”, during and after the mature phase.

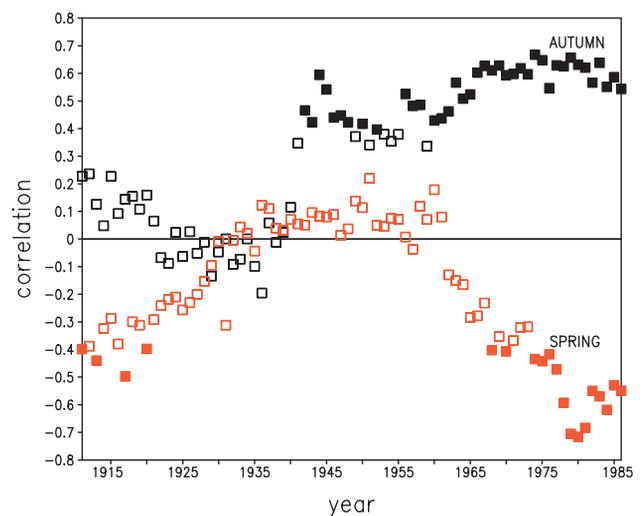
[9] We now focus on the characteristics of western Mediterranean rainfall where there is the strongest ENSO signal in the studied land domain. In Figure 3 we show the correlation between 3-month mean rainfall for this region

and the Nino3.4 index. All 4 datasets show a change of this correlation from positive in autumn to negative in spring.

[10] Warm and cold events give broadly similar but opposite western Mediterranean composite anomalies. The ENSO rainfall composite for this region, considering warm and cold events together with cold events sign reversed (see Figure 4), indicates that during an El Niño event rainfall has a 10% increase during autumn of the “year 0” (the sign of the anomaly is consistent for 18 out of the 19 analyzed events), corresponding to the rainy season arriving earlier than in climatology. In contrast, a 10% decrease in rainfall occurs in spring of the “year + 1” (14 out of 19 events), corresponding to an early rainy season retreat. Thus the total rainfall anomaly is not very large. La Niña rainfall anomalies are roughly similar but opposite in sign.

[11] Western Mediterranean autumn and spring rainfall anomalies correlate significantly with global SST anomalies giving spatially coherent patterns which, especially in the Eastern Pacific, are very similar to those invoked by a typical ENSO event (see Figure 5). ENSO-like correlation is also found in the Indian Ocean and South-East Pacific but only in autumn; in spring correlation is significant in the Western Pacific along the coast of South-East Asia. In the Atlantic, areas of significant correlation are mostly found in the sub-tropics where, close to the western Mediterranean, values are negative for both seasons.

[12] The relation between Euro-Mediterranean rainfall and ENSO has changed over the decades during the 20th century. Figure 6 shows the correlation between the Nino3.4 index and western Mediterranean rainfall for a 20-year window sliding from 1910 to 1986. Significant positive values are found for the autumn season starting from the early 1940s. For spring instead, significant positive values are only found early in the century and after the late 1960s. A lack of significant correlation for either seasons is observed during the period 1925–1940.



**Figure 6.** Correlation between western Mediterranean rainfall (CRU) and the Nino3.4 index for autumn (SON, black) and spring (MAM, red). Each value refers to the correlation for the 20-year window centered at the symbol. Full symbols are for values which are significant at the 95% level, empty symbols are for non-significant values.

#### 4. Concluding Remarks

[13] We show that there exists a significant influence of ENSO on rainfall in regions of the Euro-Mediterranean sector with seasonally changing characteristics. In addition to an ENSO-Europe connection in the spring, as noted previously, we also found significant correlation in the autumn. Although absolute anomalies are not large compared to tropical regions, the impact is relevant especially for the regions around the Mediterranean where rainfall can be scarce. For the western Mediterranean we show that ENSO events affect rainfall in an opposite manner during the autumn and the spring seasons immediately before and after the mature phase of an event. In central and eastern Europe, positive anomalies are found in winter and spring during and immediately after the mature phase. A preliminary analysis, comparing the impact of various ENSO events, does not show any clear relationship between the amplitude of the rainfall anomalies in the Euro-Mediterranean sector and the strength of the ENSO events. The rainfall anomalies in the various seasons are accompanied by an anomalous atmospheric circulation and moisture transport extending from the sub-tropical Atlantic Ocean into the Euro-Mediterranean region. In spring and autumn ENSO-like global SST anomalies are significantly correlated with western Mediterranean rainfall anomalies. However, the mechanisms of how these SST anomalies exert their influence in the far away Euro-Mediterranean region are poorly known. Our correlation results may also include contributions from modes other than ENSO, for example from the NAO [Hurrell, 1995] associated to one of the leading modes of winter-time Euro-Mediterranean rainfall variability [see e.g., Dai *et al.*, 1997].

[14] The relationship between ENSO and Euro-Mediterranean rainfall has been persistent since the latter half of the 20th century; the lack of significant correlation we find in the period 1925–1940 has also characterized ENSO teleconnections in other parts of the globe (for example Hu and Feng, 2001) and may be related to the weaker ENSO activity during this period [Urban *et al.*, 2000].

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