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NAO and winter temperature variability in southern Europe

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[1] Here we explore the relationship between the NAO and the temperatures in southern Europe, using NCEP/NCAR reanalysis data to study the synoptic situations associated with different phases and intensities of the NAO as well as with different temperature anomalies. The results show that temperatures in southern Europe are sensitive not only to the phase of the NAO, but also to the exact location of the NAO centers of action. Opposite temperature anomalies are found to be associated with similar NAO index values, leading to linear correlation coefficients between the index and the temperature series close to zero. This does not necessarily imply a negligible influence of NAO on southern European temperatures, but it may indicate a complex and non-linear relationship, not adequately represented by a simple NAO index. We conclude that the association between the NAO variability and the temperatures in southern Europe substantially differs with respect to central and northern Europe, where no such sensitivity regarding the location of the NAO action centers is found. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3319 Meteorology and Atmospheric Dynamics: General circulation; 3334 Meteorology and Atmospheric Dynamics: Middle atmosphere dynamics (0341, 0342); 3399 Meteorology and Atmospheric Dynamics: General or miscellaneous

1. Introduction

[2] Among the several modes of low-frequency variability in geopotential heights in the Northern Hemisphere, the most important one is known as the NAO (North Atlantic Oscillation) [*Barnston and Livezey*, 1987]. It is characterized by a north-south dipolar pattern of pressure anomalies, with the northern center of the dipole located over Iceland and the southern one approximately over the Azores Islands. The NAO pattern is most pronounced both in intensity and in area coverage during the winter and presents two phases: the positive phase reflects heights and pressures which are below normal across the high latitudes of the North Atlantic and above-normal over the central North Atlantic; the negative phase is characterized by an opposite pattern.

[3] The climatic effects of the NAO in the North Atlantic region have been widely studied in recent years, revealing it to be the most important source of climate variability in Europe [*Hurrell*, 1995; *Osborn et al.*, 1999]. Particularly, the interannual temperature variability in central and northern Europe is substantially induced by changes in the NAO. Also, in northern Africa an influence of the NAO on the temperature [*Rogers*, 1997] and dust storms [*Moulin et al.*, 1997] has been reported. However, the influence of NAO on the southern European climate is not clear, as several studies show a definite influence on precipitation [*Lamb and Peppler*, 1987; *Rodó et al.*, 1997; *Hurrell and van Loon*, 1997; *Rodrigo et al.*, 2001; *Esteban-Parra et al.*, 1998] but very weak links to the temperatures [*Hurrell and van Loon*, 1997; *Osborn et al.*, 1999]. To explore the distinct behavior in southern Europe, we have studied the relationship between the NAO and temperatures and we have compared the synoptic situations associated with different phases and intensities of NAO and with different temperature anomalies.

2. Data and Previous Analysis

[4] Gridded winter air-temperature data from 1852 to 1997 from the North Atlantic land regions, comprising western, central and southern Europe, southern Scandinavia, and North Africa (Long. 10°W to 20°E; Lat. 35°N to 60°N), have been analyzed. The data (provided by the CRU, Univ. of East Anglia, U.K.) are defined on a 5° latitude by 5° longitude grid-box basis and are expressed as anomalies from the corresponding monthly averages of the period 1961–90 [*Jones*, 1994]. Winter temperatures (Dec. to Feb.) were determined by averaging the corresponding monthly values.

[5] A winter index, calculated with pressure data from Gibraltar and Iceland [*Jones et al.*, 1997], normalized relative to the period 1951–1980 was used to monitor the NAO. The way in which the index was formulated, the reasons for using this particular index and its main characteristics are discussed in *Pozo-Vázquez et al.* [2000].

[6] In a previous work [*Pozo-Vázquez et al.*, 2001], the relationships between spatial and temporal modes of European winter temperature variability and the NAO were analyzed for the period 1852–1997 using the former data basis. A PCA showed that the most important mode of spatial variability of the winter temperatures (38.1% explained variance) can be identified with the NAO. This mode represents mainly the variability of western and central Europe, southern Scandinavia and the British Isles. Figure 1 top shows the loading factors. The correlation coefficient between the NAO index and the corresponding PC series is 0.8 (statistically significant at 95%). Thus, a clear association between the climate of central and northern Europe and the NAO is found. The variability of the temperatures in southern Europe is represented by the second mode, for which the loading factors are shown in Figure 1 bottom. The correlation between the NAO index and the PC series is 0.06 (not significant).

[7] Besides, SLP and zonal (U) and meridional (V) wind surface NCEP/NCAR reanalysis data have been used here, covering the region from 30°N to 80°N and 60°W to 40°E. The initial 2.5° by 2.5° grid-box resolution was reduced to 5° latitude by 10° longitude. The analyzed period is 1959–1997 and the data are expressed as anomalies relative to the period 1961–90. Winter averaged anomalies were obtained by averaging the monthly anomalies as for the temperature data.

3. Analysis and Discussion

[8] Firstly, we compared the SLP patterns associated with the NAO and temperatures. Figure 2 shows the sample correlations between the winter PC temperature anomaly series associated with southern Europe and the SLP field in the North Atlantic region (bottom) and between the winter NAO index and the SLP field (top). The period analyzed was 1959–1997.

[9] The spatial correlation patterns proved different: the well-known dipolar structure of the NAO is seen in Figure 2 top, but Figure 2 bottom presents a different structure of the SLP associated

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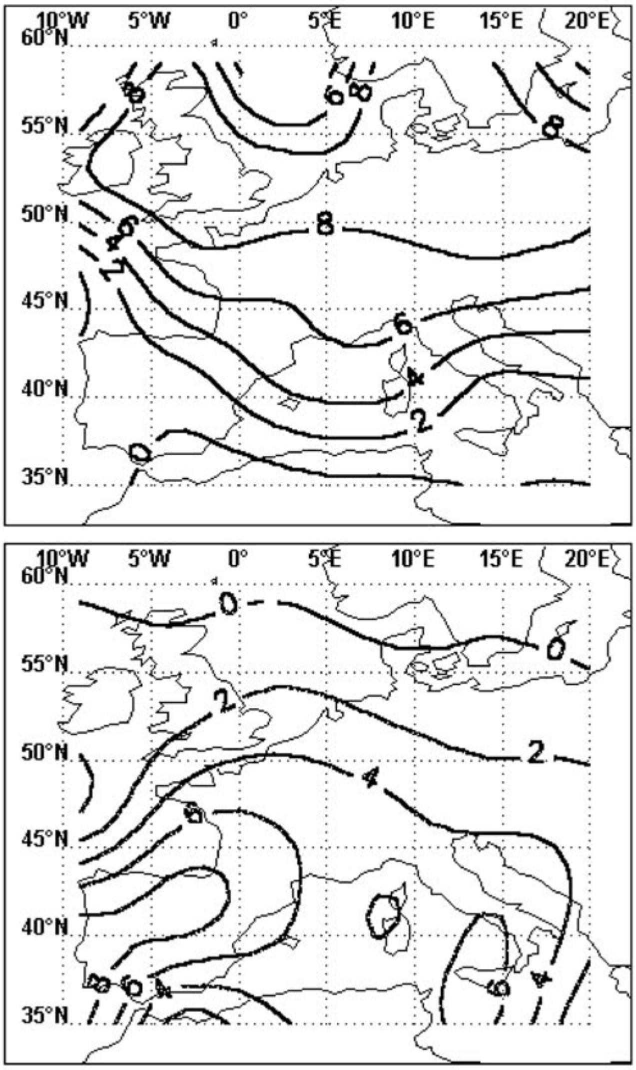

Figure 1. Loading factors (by 10) for the first (top) and second (bottom) REOF resulting from the analysis of the winter temperatures during the period 1852–1997.

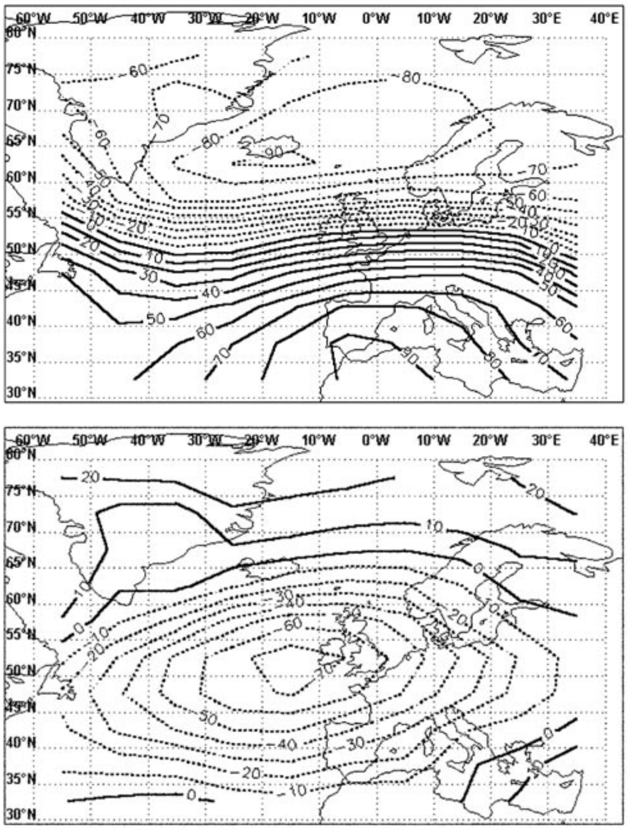

Figure 2. (top) Correlation (by 100) between the NAO index and the SLP field in the North Atlantic. The continuous line indicates positive or zero loading and the dotted line indicates negative loading. (bottom) Correlation value (by 100) between the PC temperature series associated with southern Europe and the SLP field in the North Atlantic region. A 0.16 standard error can be assumed for the estimates.

with temperature variability in southern Europe. This area shows a negative correlation with the SLP in the central North Atlantic. The correlation pattern has a circular structure, with its core south of Ireland, where correlations reach −0.7. Positive temperature anomalies are associated with negative SLP anomalies south of Ireland, bringing relatively warm maritime air from the Atlantic to southern Europe. On the other hand, negative temperature anomalies are associated with positive SLP anomalies, which cause northeast wind anomalies over southern Europe.

[10] It is noteworthy that the core of the correlation pattern in Figure 2 bottom is located in the region of the strongest correlation gradient in Figure 2 top, so that it covers both positively and negatively correlated areas. Hence a shift in the location of the NAO action centers can lead to significantly different SLP anomalies south of Ireland, with possible sign changes. This analysis gives an explanation for the negligible correlation value between the temperatures in southern Europe and the NAO, since small variations in the location of the NAO action centers lead to different SLP anomalies south of Ireland and thus can give rise to different temperature anomalies in southern Europe.

[11] To go further in this study, we have carried out an additional analysis, studying some particular cases. Figure 3 shows the NAO index and the PC series corresponding to southern Europe during the period 1950–1997. We have selected six particular winters because they constitute an example of the controversial relationship between the NAO and the temperatures in southern Europe. Figure 4 shows

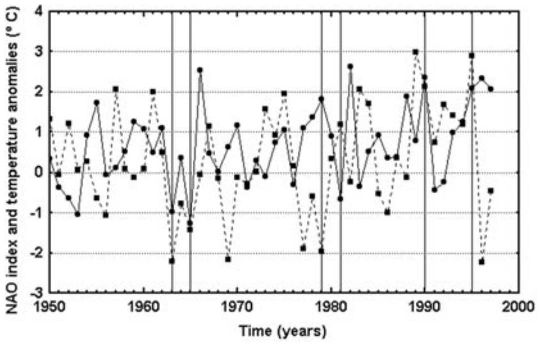

Figure 3. Winter NAO index (dashed line) and PC series corresponding to REOF associated with southern Europe (continuous line). Units are Celsius degrees (anomalies) for the PC series and standard deviation units for the winter NAO index. The period represented is 1950–1997. Vertical continous lines correspond to the selected cases.

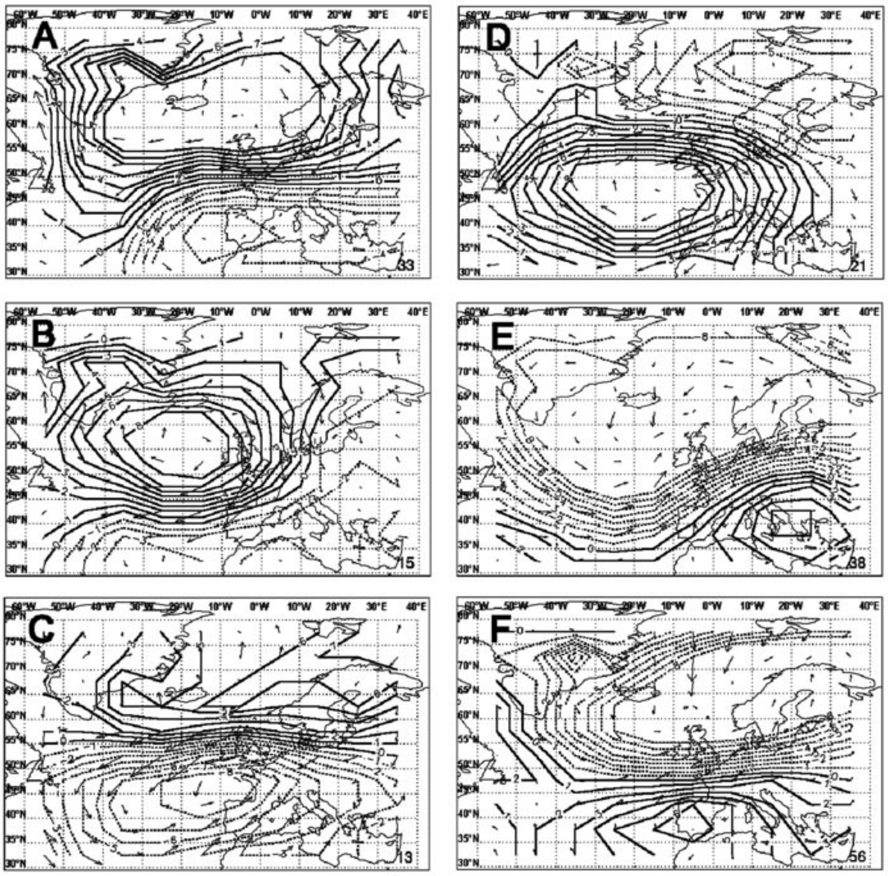

Figure 4. Wind-surface and SLP anomalies in the North Atlantic region for the winter of A) 1963, B) 1965, C) 1979, D) 1981, E) 1990 and F) 1995. Indicated SLP values are anomalies in milibars, with a contour interval of 1. The continuous line indicates positive or zero anomalies and the dotted line indicates negative anomalies. The maximum wind surface anomalies, in m/s and multiplied by ten, are indicated in the bottom right-hand corner.

the SLP and wind surface anomalies associated with the selected cases: A) 1963, B) 1965, C) 1979, D) 1981, E) 1990 and F) 1995.

[12] During the winter of 1963 (Figure 4A) an extreme negative phase of the NAO is discernible (NAO index −2.2). The northeastern wind surface anomalies over southern Europe clearly resemble the negative NAO phase dipolar pattern. As a consequence of these circulation anomalies, negative temperature anomalies are found over this area; in particular, the anomaly of the PC temperature series is −1°C. Figure 4B illustrates the synoptic situation during the winter of 1965. Again, a negative phase of the NAO occurs (NAO index −1.4). The wind and SLP patterns show a different structure, compared with the previous case, the NAO dipolar structure not being so clear as before. The northern positive anomaly center is located south of the preceding case, while the southern center appears very weak. This pattern leads again to northeastern wind anomalies over southern Europe. The associated PC temperature anomaly is −1.3°C. The pattern in Figure 4C shows the situation for the winter of 1979. Again, there is a negative NAO index value of −2.0. The patterns of wind and SLP anomalies again clearly resemble the NAO negative phase. Nevertheless, the more northern location of the southern center of action differs substantially from the previous cases and leads to strong south-western wind anomalies which bring warm air to southern Europe. This results in high temperatures in southern Europe, in particular there is a +1.8°C anomaly of the PC temperature series.

[13] A similar analysis was made for the positive phase of the NAO. Figure 4D shows the synoptic situation during the winter of 1981, with a positive NAO index value of 1.2. The wind surface and SLP anomalies patterns show a strong core of positive SLP anomalies southwest of Ireland, leading to northeastern wind anomalies over southern Europe. The PC temperature anomaly series shows a value of −0.8°C. During the winter of 1990 (Figure 4E), again a positive phase of the NAO takes place (index value 2.1). The great extension of the core of negative SLP anomalies over Iceland and the strong SLP gradient located between Ireland and the Iberian Peninsula lead to strong south-western warm wind anomalies over southern Europe (also over central an northern Europe). As a result, the PC temperature anomaly series shows, contrary to the previous case, a very high positive value, +2.2°C. Finally, Figure 4F shows the synoptic situation during the winter of 1995. A very strong positive phase of the NAO appears (with an index value of 2.9). The wind and SLP anomalies pattern clearly shows the NAO dipolar pattern. The location of the action centers lead to relatively low south-western wind surface anomalies over southern Europe. The PC shows a positive anomaly of 2°C.

[14] In summary, the southern European temperature appears to be highly sensitive to the location of the NAO action centers during the same (positive/negative) NAO phase. Depending not only on their phase, but also on the location of NAO action centers, positive or negative temperature anomalies can be found associated with both positive and negative phases of the NAO.

[15] On the other hand, over central and particularly over northern Europe, no such sensitivity is found. Figures 4D, 4E and 4F indicate

that over these areas, the westerly component of the wind is always present during the positive phase of the NAO, leading to positive temperature anomalies, meanwhile during the negative NAO phase (Figures 4A, 4B and 4C) the prevailing circulation brings cool continental air, leading to negative temperature anomalies.

[16] As noted before, there is a clear different influence of the NAO on precipitation and temperature in southern Europe. An additional study carried out using precipitation anomalies of the Iberian Peninsula (not shown) reveals that the precipitation variability seems to be more clearly affected by circulation conditions linked to the NAO than temperature variability does, probably because the temperature is also ruled by other sources of variability, as the radiative one.

4. Concluding Remarks

[17] The influence of the NAO in the temperature variability in southern Europe is more complex than over central and northern Europe, being extremely sensitive to the location of the SLP anomaly centers. Central and northern Europe do not show such sensitivity due to their location, in the region of the strongest SLP gradient. Since a simple NAO index represents mainly this SLP gradient, correlation between this index and temperatures over central and northern Europe presents a very markedly positive value. On the other hand, for southern Europe, not only the gradient value but also the location of the action centers matters, a simple index of the NAO shows linear correlation coefficient approaching zero. But this does not signify that the NAO has negligible influence on southern European temperatures, but simply that this relationship is more complex than for central and northern Europe and that a simple index cannot adequately represent the NAO in many situations. Furthermore, the position on the NAO action centers seems to change from year to year [*Mchel et al.*, 1998; *Davis et al.*, 1997]. This contributes to a different behavior of the temperatures in southern Europe with respect to central and northern Europe at the temporal scales of the NAO variability.

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References

Barnston, A. G., and R. E. Livezey, Classification, Seasonality and Persistence of Low-Frequency Atmospheric Circulation Patterns, *Mon. Wea. Rev.*, *115*, 1083–1126, 1987.

Davis, R. E., B. Hayden, D. Gay, W. Phillips, and G. Jones, The North Atlantic subtropical anticyclone, *J. Climate*, *10*, 728–744, 1997.

Esteban-Parra, M. J., F. S. Rodrigo, and Y. Castro-Díez, Spatial and temporal patterns of precipitation in Spain for the period 1880-1992, *Int. J. Climatol.*, *18*, 1557–1574, 1998.

Hurrell, J. M., Decadal trends in North Atlantic Oscillation and relationship to regional temperature and precipitation, *Science*, *269*, 676–679, 1995.

Hurrell, J. M., and H. van Loon, Decadal variations in climate associated with the North Atlantic Oscillation, *Climatic Change*, *36*, 301–326, 1997.

Jones, P. D., Hemispheric surface air temperature variations: A reanalysis and an update to 1993, *J. Climate*, *7*, 1794–1802, 1994.

Jones, P. D., T. Jonsson, and D. Wheeler, Extension to the north Atlantic Oscillation index using early instrumental pressure observations from Gibraltar and South-West Iceland, *Int. J. Climatol.*, *17*, 1–18, 1997.

Lamb, P. J., and R. A. Peppler, North Atlantic Oscillation: Concept and an Application, *Bull. Amer. Meteor. Soc.*, *68*, 1218–1225, 1987.

Mchel, H., A. Kapala, and G. Flohn, Behaviour of the centres of action above the Atlantic since 1881. Part I: Characteristic of seasonal and interannual variability, *Int. J. Climatol.*, *18*, 1–22, 1998.

Moulin, C., C. E. Lambert, F. Dulac, and U. Dayan, Control of atmospheric export of dust from North Africa by the North Atlantic Oscillation, *Nature*, *387*, 691–694, 1997.

Osborn, T. J., K. Briffa, S. F. B. Tett, P. D. Jones, and R. M. Trigo, Evaluation of the North Atlantic Oscillation as simulated by a climate model, *Clim. Dyn.*, *15*, 685–702, 1999.

Pozo-Vázquez, D., M. J. Esteban-Parra, F. S. Rodrigo, and Y. Castro-Díez, An analysis of the variability of the North Atlantic Oscillation in the time and the frequency domains, *Int. J. Climatol.*, *20*, 1675–1992, 2000.

Pozo-Vázquez, D., M. J. Esteban-Parra, F. S. Rodrigo, and Y. Castro-Díez, A study on NAO variability and its possible non-linear influences on European surface temperatures, *Clim. Dyn.*, *17*, 701–715, 2001.

Rodó, X., E. Baert, and F. A. Comin, Variations in seasonal rainfall in Southern Europe duirng the present century: realtionships with the North Atlantic Oscillation and the El Nio-Sourthern Oscillation, *Clim. Dyn.*, *13*, 275–284, 1997.

Rodrigo, F. S., D. Pozo-Vázquez, M. J. Esteban-Parra, and Y. Castro-Díez, A reconstruction of the winter North Atlantic Oscillation index back to A.D. 1501 using documentary data in southern Spain, *J. Geophys. Res.*, *14*, 805–818, 2001.

Rogers, J. C., North Atlantic Storm Track Variability and Its Association to the North Atlantic Oscillation and Climate Variability of Northern Europe, *J. Climate*, *10*, 1635–1647, 1997.

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