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# NAO INFLUENCE ON MAXIMUM AND MINIMUM TEMPERATURE OF THE IBERIAN PENINSULA

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## ABSTRACT

Recently, it has been shown the important impact of the North Atlantic Oscillation (NAO) in both maximum and minimum temperatures over Europe. Using the NCEP-NCAR Reanalysis comprehensive dataset between 1958 and 1997 we show that NAO-related temperature patterns are mainly controlled by the advection of heat by the anomalous mean flow. However, asymmetries between minimum and maximum temperatures, and also between positive and negative phases of NAO imply the importance of a different mechanism, namely the modulation of short wave and long wave radiation by cloud cover variations associated with the NAO. Here we intend to study in greater detail the impact of NAO mode on the Iberian maximum and minimum temperature fields.

The long maximum and minimum temperature series of the Iberian Peninsula are analyzed covering the period 1900-2000. To identify coherent behaviour in these series, the PCA method has been used, resulting in several major noise-filtered time series. For maximum and minimum temperatures two statistically significant EOFs have been obtained with high loading values over the western and eastern parts of the Iberian Peninsula. However, the spatio-temporal variability of the entire region can be described by the first EOF and its time evolution by the corresponding PC series. Minimum temperature series shows a general upward trend, meanwhile maximum one presents a strong increase since the 1970s.

The relationships between extreme temperature and the NAO index were studied on a seasonal basis. For this purpose, we computed the NAO index using Gibraltar pressure data as the southern location for winter and Ponta Delgada (Azores) for the remaining seasons. Only for the winter (DJF) the correlation coefficients are significant (at the 5% level), with values of 0.35 and –0.18 for maximum and minimum temperatures respectively. The opposite signs for these correlation coefficients reflect the fact that, for positive (negative) NAO winter months, the Iberian Peninsula experience anomalously anticyclonic (cyclonic) circulation and reduced (enhanced) precipitation, and these are associated with reduced (enhanced) cloud cover. Thus, when NAO index is positive, the additional daytime incoming solar radiation increases the maximum temperature, while the corresponding night-time minimum temperature decreases due to outgoing long-wave radiation. For the other seasons, no significant correlations are found.

On the other hand, these relationships are non stationary, changing markedly over time. There seems to be an increase on the influence of the NAO pattern on the Iberian temperatures during the last 30 years. In order to explore in more detail this fact, we are currently studying the impact of NAO on cloudiness during the entire period 1901-1995 using the recently developed high resolution (0.5º lat. × 0.5º lon.) database by CRU.

## 1. INTRODUCTION

The most common variable analyzed to assess climatic change due to increased greenhouse gases in the atmosphere is the average global temperature. The series of this variable present a significant rise during the period of instrumental records, by more than 0.6 ºC over the past 135 years (Jones et al., 1994). This variable, the average temperature, is an agent in environmental changes (Hansen et al., 1995). Predicted increase in global temperature based on numerical models, is between 0.6 and 0.4º C over the next 25 years (IPCC, 1995), together with effects, which are not very well understood, so, for example, a most critical need is to investigate whether global warming will cause changes in regional climate. This implies the need to examine local changes and relate then to different possible environmental impact of the climatic change in each region. Furthermore, to improve our knowledge of the climate, research is needed on local and regional scales (Karl et al., 1989). The use of empirical methods can reveal major patterns and provide qualitative estimates of the form and range of the regional climate change useful to validate climatic models with a physical basis (Giorgi and Mearns, 1991).

In the present work, the mean temperature records throughout Iberian Peninsula are analysed. The climatic studies over this region have particular interest, due to the geographical position of the Iberian Peninsula, between the Atlantic Ocean and the Mediterranean Sea, and between the continents Africa and Europe. In addition, this region is located in the circumpolar vortex border and its climate is closely linked with the atmospheric circulation. The climatic variability of this area is also of interest due the current problems provoked by droughts and other extreme events, which have been discussed by some authors (Katz and Brown, 1992) as good indicators of the climatic change and by the adverse predictions of the models in the Mediterranean area (IPCC, 1995). It is important to identify regions with similar behavior, detect and quantify possible changes and relate them with possible causal mechanics. The present paper undertakes this task for the case of Iberian Peninsula.

## 2. DATA

The database used in this study includes annual and seasonal mean, maximum and minimum air temperature and precipitation for 42 Iberian localities, including Baleares Islands. They were selected from 65 series supplied by the Instituto Nacional de Meteorología (INM), attending quality criteria. We use Lisbon and Coimbra data from Portugal. The temporal coverage analysed is 1880-1997.

Most of the stations have not changed their position, but only for a few of them we know the metadata related to methods and instruments. Homogeneity problems are common in temperature records. Some of the annual and seasonal series present homogeneity problems that were corrected using the method proposed by Bradley et al. (1985), taking into account the difference between the mean values before and after the inhomogeneity, and when possible, nearby stations. In the correction, periods without trends or other effects were used, following the recommendations of Rhoades and Salinger (1993).The details of these corrections can be found in Esteban-Parra (1995) and Esteban-Parra and Castro-Díez (1996).

Series with few missing values have been used (less than 3 consecutive years). The missing data have been filled in with the corresponding monthly mean value of the missing month calculated for the entire period.

To study the relationship between temperature and NAO, we used the NAO index taking Gibraltar pressure data as the southern location for winter (Jones et al, 1997) and Ponta Delgada (Azores) for the remaining seasons. Pozo-Vázquez et al. (2000), discuss the reasons of this election of the southern location depending on the season of the year.

We used the data cloudiness recently developed by CRU (New et al., 1999, 2000). This is a high resolution (0.5º lat. × 0.5º lon.) database, covering the period 1901-1995. This data set uses a dense network of observations, particularly over Europe and for the period that spans the early 1960s to the early 1990s (New et al., 2000).

## 3. METHOD

To identify the general behaviour of all the series, the Principal Component Analysis, PCA, was applied (Preisendorfer, 1988). Briefly, given p variables (anomalies) of length n corresponding for example to p locations, the method consists of the diagonalization of the covariance/correlation matrix. The EOFs (Empirical Orthogonal Functions) are the eigenvectors with an associated variance equal to their corresponding eigenvalue.

The rule N (Preisendorfer, 1988) was applied in order to select the number of the significant EOFs. This is a MonteCarlo procedure to obtain the eigenvalue distribution of random covariance matrix. An alternative and possibly better interpretation of the results can be attained by rotating the significant EOFs by the Varimax procedure (Preisendorfer, 1988).

## 4. TEMPERATURE ANALYSIS

EOF patterns

Except for winter (always computed averaging December, January and February), which has only one significant EOF, two significant EOFs were found for the rest of the seasonal and annual series. At this point we should note that the first unrotated EOF explains most of the variance (more than the 50%) with high correlations for all the stations, and the second one less than the 10%, with significant correlations for stations on the Mediterranean and East Cantabric coasts. When we rotate these EOFs, the second has the effect of pulling the first, in such a way that in some cases the rotation divides the first unrotated EOF into two. Both have significant correlations for almost all the stations, although the first rotated EOF represents slightly better the western part and the second the eastern part. This is the case for example of the annual data, and to lesser extend for summer data that is, the regions most influenced by Atlantic weather types, and by the Mediterranean climate. In any case, the regionalization drawn by these two rotated EOFs is quite limited and the first unrotated EOF can be considered representative of the entire area under study.

PCA series

Figure 1 shows the seasonal PC series for minimum and maximum temperature with their corresponding smoothed series, identifying the longer-term variability.

For the maximum temperature, during winter, a very cold period ocurred at the end of last century, followed by a long period (until the end of 1950s) with average values slightly below the mean. The 1960s presented values above normal and, from the end of the 1970s until the end of the series, there was a warm period. The spring and summer series show a cold period at the end of 19th century, while the first decade of this century was warm, followed by cold years until the 1920s. The 1930s can be considered as normal with respect to the entire period, whereas, the 40s, 50s and part of the 60s were all very warm. The decade of the 1970s was very cold, followed by the relatively warmer 1980s. Autumn shows similar fluctuations, with a remarkable intensity of warm period during the decades of the 1940s and 1950s. The cold period of the 1970s was shorter and less intense, there was a strong increase in the temperatures during the 1980s. Only for this season, the Mann-Kendall test detects a significant trend at 95% level.

The maximum temperature annual series summarizes this behaviour, showing an increasing trend until 1970, superimposed over the cold/warm periods. There were remarkable cold conditions at the end of the last century and during the 1970s, followed by the strong warming in the final years of the series.

Minimum temperatures show similar fluctuations, with a very significant increased trends in all the seasons, as Mann-Kendall test shows. In any case, it is remarkable the greater increase of the maximum temperature since the 1970s.

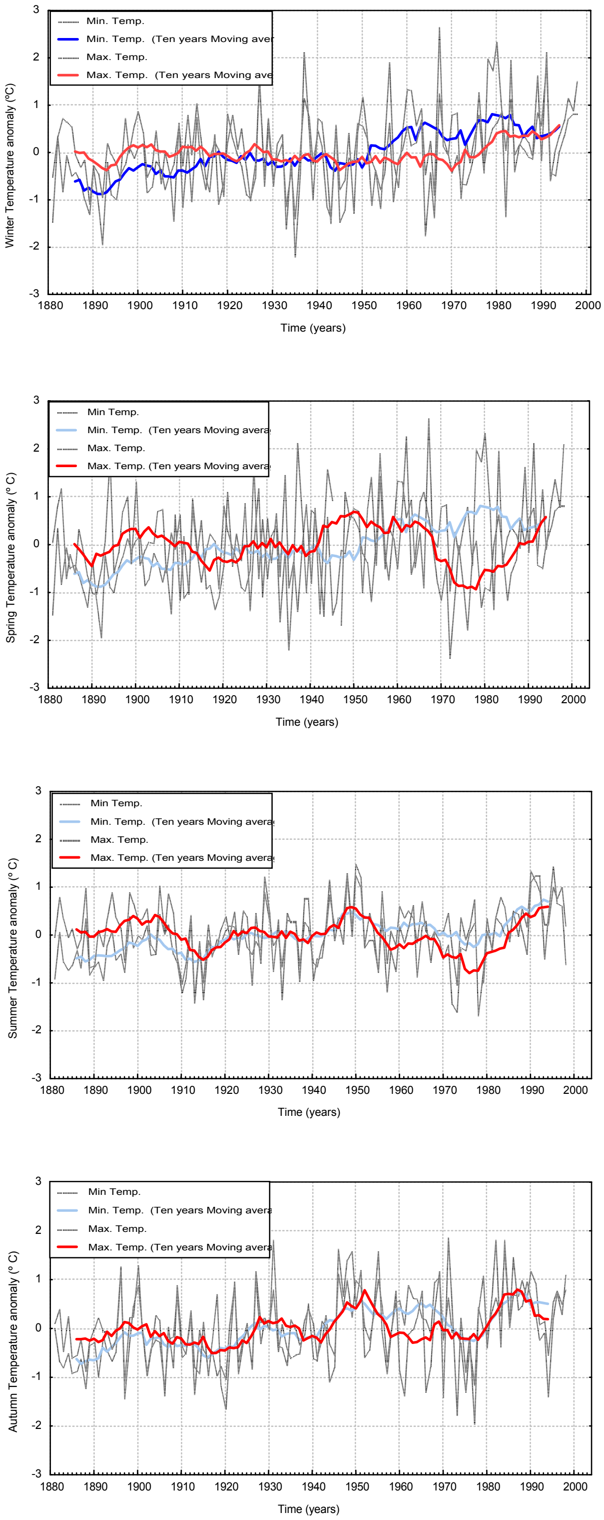


**Figure 1**: Seasonal PC series for maximum and minimum temperature (dashed lines) and their corresponding moving 10 year average series (solid line), identifying the longer-term variability.

A partial explanation of the increase found in minimum temperatures is the so-called urban island effect. In the present work the most part of the localities correspond to urban sites. Most are small cities (41.5% of these localities have less than 100.000 inhabitants, and 22% less than 50.000 inhabitants). It is true that urban heating is also present in small localities as demonstrated by Karl et al.(1988), but this conclusion loses validity for cities with a very long history, as it is in this case. Urban growth has not had a constant rate, and thus, it is not possible to consider a linear trend. At least in Spain, growth has been greater during this century, especially since 1960, when the cities began to develop modern features, such as the presence of asphalt and industry. In addition, the number of cities with more than 100.000 inhabitants rose in the1970s, although the warming began before, around 1920. Also, the cooling in the 1970s does not seem masked by the urban heating. According to Jones et al. (1986), at least at hemispheric scale, the effect of the urbanism is less than 0.1 ºC. The urban island effect is perhaps responsible for the temperature increase in Spain at a similar rate.

Relationships with NAO

With regard to the relationships between temperature and NAO and circulation conditions, Table 1 shows the correlations between maximum and minimum temperatures series and the NAO index using Gibraltar pressure data as the southern location for winter (Jones et al, 1997) and Ponta Delgada (Azores) for the remaining seasons. The reasons for using different southern location data depending on the season can be read in Pozo-Vázquez et al., 2000.

| | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|
| $T_{max}$ | 0.38* | 0.02 | -0.07 | 0.02 |
| $T_{min}$ | -0.18* | -0.04 | -0.02 | -0.06 |

**Table 1**: Correlations between seasonal NAO index and the first PC series of maximum and minimum temperature. * means significant correlation at 95% level.

Only for winter, correlations are significant, although low, specially for minimum temperature. This is a little surprising, bearing in mind that circulation conditions have been proposed as an important temperature variability agent during the cold season (Wallace et al., 1995). In fact, precipitation over the area is controlled mainly by the NAO (Esteban-Parra et al., 1998). On the other hand, correlation with maximum temperature is positive, meanwhile it is negative with the minimum temperature**.** This situation may be due to different effects on maximum and minimum winter temperatures: during high pressure and high NAO conditions, maximum temperatures increases due to solar heating, whereas minima decrease due to radiative cooling, and thus, for low NAO and low pressure conditions, the reverse is true with regard the temperature behaviour. This fact provokes, for instance, the low correlation between NAO and mean winter temperature for Spain reported by other researchers (Castro-Díez et al., 2002).

The opposite signs for these correlation coefficients reflect the fact that, for positive (negative) NAO winter months, the Iberian Peninsula experience anomalously anticyclonic (cyclonic) circulation and reduced (enhanced) precipitation, and these are associated with reduced (enhanced) cloud cover. Thus, when NAO index is positive, the additional daytime incoming solar radiation increases the maximum temperature, while the corresponding night-time minimum temperature decreases due to outgoing long-wave radiation. For the other seasons, no significant correlations are found.

We have also analysed stationary of the relationships between NAO and the temperatures. For this purpose, we have computed 50 year moving correlations between seasonal NAO indices and the seasonal PC series. Only for winter, the correlations are significant, for the rest of the seasons, correlations are always very close to zero. Figure 2 shows the moving correlation for winter.

We can see that in general, the relationship between maximum temperature in the Iberian Peninsula and NAO index was quite stable. The relation was worse around the period 1890-1940. High correlations appear in the last 50 years correlations, close to 0.5. On the other hand, correlation between minimum temperature and NAO has changed markedly. Except in the first years, correlations are negative, but only significant since 1960, with values around –0.2.

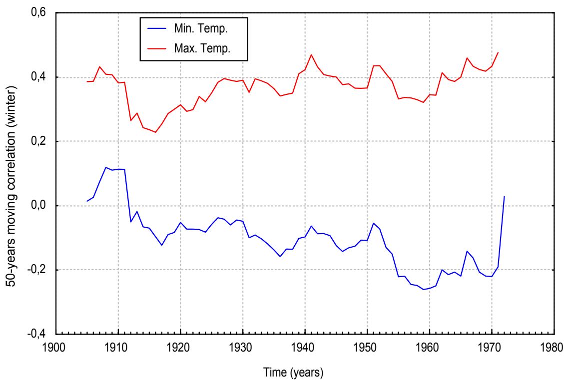


**Figure 2**: 50 year moving correlations between winter PC temperatures series and winter NAO index.

<u>Cloudiness analysis</u>

In order to explore in more detail these changed relationships between NAO and Iberian temperatures, we have also analysed the relationship between cloud cover and NAO index, using data recently developed by CRU (New et al., 1999, 2000). This is a high resolution (0.5º lat. x 0.5º lon.) database, covering the period 1901-1995. This data set uses a dense network of observations, particularly over Europe and for the period that spans the early 1960s to the early 1990s (New et al., 2000).

With this database, composites of the cloud cover during winter were made based on the selected NAO extreme events (NAO>1 and NAO<-1). 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 to compare the composites of cloud cover of the selected NAO>1 seasons and NAO<-1 seasons. The test takes into account eventual different lengths of the series compared.

Results are particularly significant for winter. Figure 3 show the composites of cloud cover for (a) winter NAO index>1, (b) winter NAO index<-1, and (c) the difference (a)-(b), for the period 1960-1995. For NAO>1, cloudiness anomalies are negative, as it is expected, reaching values of -0.4 oktas in the Southwestern Iberia (Figure 3a). For NAO <-1, the cloudiness anomalies are positive and smaller, with the highest values in the southwest (Figure 3b). The difference of these two composites (Figure 3c) is significant at 95% level for Southwest and interior part of Iberian Peninsula. Similar results are found by Trigo et al., (2002). This is the NAO influence area on the precipitation in the Iberian Peninsula (Esteban-Parra et al., 1998) and confirm the discussion above mentioned. Results are similar for spring and autumn, with lower anomalies and being the difference significant only in the southwest.

For the period 1901-1959, no significant differences are found in cloud cover for NAO >1 and NAO <-1 in any season. This could explain the changes in the relationships between the NAO and Iberian maximum and minimum temperatures, shown by the 50 years moving correlations. However, we have to take in consideration that the cloudiness data used is less reliable in this period.

## 5. SUMMARY AND CONCLUSIONS

Maximum and minimum temperature data covering the Iberian Peninsula during the period 1880-1997 have been analysed, showing a coherent temporal behavior all the region.

Correlations between the first PC series of maximum and minimum temperatures and NAO index have been computed for all the seasons. Only for winter, correlations are significant, positive for maximum temperature, and negative for minimum one. The opposite signs for these correlation coefficients reflect the fact that, for positive (negative) NAO winter months, the Iberian Peninsula experience anomalously anticyclonic (cyclonic) circulation and reduced (enhanced) precipitation, and these are associated with reduced (enhanced) cloud cover. Thus, when NAO index is positive, the additional daytime incoming solar radiation increases the maximum temperature, while the corresponding night-time minimum temperature decreases due to outgoing long-wave radiation. This is also confirmed by the analysis of the cloudiness data for lower than expected, taking in mind the high impact of NAO on the Iberian precipitation during winter. For the other seasons, no significant correlations are found.

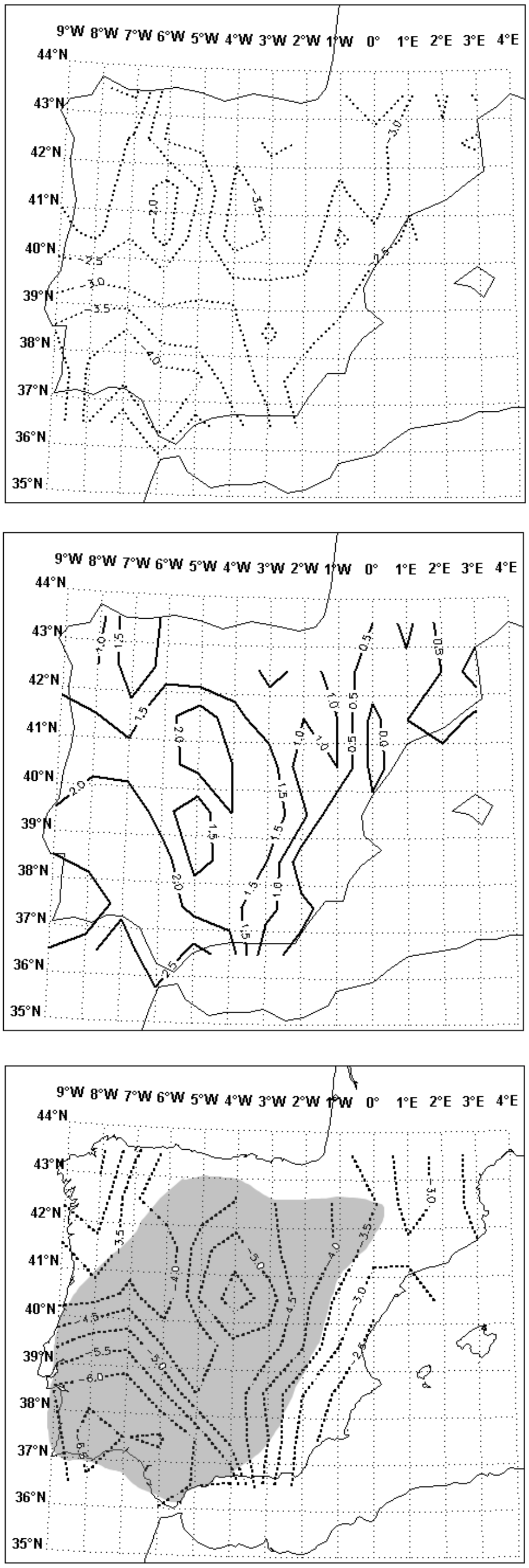

Figure 3: Composites of winter cloudiness for (a) winter NAO index >1, (b) winter NAO index<-1, and (c) the difference (a)-(b). Units are tenths of oktas.

On the other hand, the relationship between NAO and the temperature are not stationary, particularly the correlation between minimum temperature and NAO has changed markedly, being more important in the last parts of the period.

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, as shown by Castro-Díez et al. (2002) and Pozo-Vázquez et al. (2001). Central and northern Europe do not show such sensitiveness 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 cares. 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 (Mächel 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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