INTERANNUAL VARIABILITY OF THE ANNUAL CYCLE OF TEMPERATURE OVER NORTHERN AFRICA

M. TESOURO[1], L. GIMENO[1*], R. NIETO[1], L. DE LA TORRE[1], P. RIBERA[2], D. GALLEGO[2], R. GARCÍA-HERRERA[3], E. HERNÁNDEZ[3]

1 Universidad de Vigo, Departamento de Física Aplicada, Facultad de Ciencias de Ourense, 32004, Ourense, Spain (l.gimeno@uvigo.es)

2 Universidad Pablo de Olavide, Departamento de Ciencias Ambientales, Sevilla, Spain

3 Universidad Complutense de Madrid, Departamento de Física de la Tierra II, Madrid, Spain

* Corresponding author

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ABSTRACT

In this study, the imprints of two major atmospheric variability modes - ENSO and NAO - on the annual cycle of temperature over Northern Africa, a region sensitive to both modes, are investigated. Results from adjusting the annual cycle from daily data on a high resolution grid, indicate that both NAO and ENSO are able to influence significantly the amplitude and phase of the seasonal cycle and, consequently, that interannual trends found in amplitude and phase can be not exclusively due to greenhouse gases effects.

Keywords: climatology, seasonal cycle, ENSO, NAO

1. INTRODUCTION

An increasing interest has risen recently in estimating interannual variability of the annual cycle of temperature. This is due to its role in controlling a number of other variables, such as pressure patterns or circulation characteristics. Both amplitude and phase of the annual cycle have been analysed and results suggest that none of them can be simply explained by solar insolation variability (*Mokhov and Eliseev, 1997; Eliseev et al., 2000; Eliseev et al., 2003*). Should this be confirmed, a change due to anthropogenic reasons could be a reasonable hypothesis. Perhaps the starting point of this idea comes from two papers published in 1995 (*Thomson, 1995 and Thompson, 1995*). The former found changes in the phase of the annual cycle during the last century, different to those expected according to the insolation variability. The latter found a distinct decrease in annual cycle amplitude in European temperature records during the 1920s. When comparing observed with simulated data (*Mann and Park, 1996; Wallace and Osborn, 2002*) there is an agreement in the decrease of the amplitude under carbon dioxide increments but a disagreement in the phase trends (in observed data, phase advances; while in simulated data, phase delays). The lack of high-latitude sampling in the observed data could be the reason of the disagreement between observed and simulated data, however there is an agreement in mid-latitudes. An increment in the ice-albedo feedback has been hypothesized as responsible for the changes of amplitude while the increase of greenhouse gases has been hypothesized as responsible for the phase advances in mid-latitudes. However, due to the fact that the two dominant modes of interannual climate variability, ENSO for the tropics and NAO for the extratropical Northern Hemisphere, exhibit clear seasonality and have strong influence on atmospheric temperature (*Marshall et al., 2001; Diaz et al., 2001*), the idea that a significant percentage of the interannual variability of the annual cycle of the temperature could be attributed to natural modes of climate variability should not be disregarded.

Africa is a vast continent whose location, size and shape determine a wide variety of climate regimes. The Northern and Southern extremes of the continent have climatic conditions closely associated with the passage of mid-latitude air masses. Over the rest of the continent, the annual cycle is strongly determined by the position of the Inter-Tropical Convergence Zone (ITCZ). However, interannual variations in the ITCZ could be coupled with higher latitude climate fluctuations through the teleconnections supported by the Hadley circulation. So, Africa may be subdivided into several regions for studies of interannual variability, characterized by different forms of topography, vegetation, and land-sea contrasts that determine strong regional climate differences. The dynamical mechanisms responsible for seasonal to interannual variability of these regional climate are also different (*Xoplaki et al., 2003*). One of those regions could be Northwestern Africa, whose climate anomalies are strongly correlated with North Atlantic Oscillation (NAO). So the winter rainfall regimes of extreme Northern latitudes of Africa are driven by the passage of mid-latitude frontal perturbations and the decadal fluctuations of rainfall in subtropical Northwestern Africa (*Ward et al., 1999*), seem to be correlated with decadal fluctuations in the North Atlantic Oscillation (NAO) (*Hurrell, 1995*). High Moroccan rainfall (November-April) tends to coincide with large negative values of the NAO index. Another region could be Northeastern Africa, which is characterized by semi-arid or arid climatic conditions and strongly influenced by ENSO. The river Nile controls the hydrological variability over the region and 30% of the natural variability in the Nile's water-level fluctuations could be linked to El Niño. In fact, the Nile's height has been used as an indicator of El Niño years in preinstrumental periods (*Eltahir, 1996*).

Thus, Northern Africa is a region that can be designated as a separate region for climate variability studies. In particular, the fact that Northern Africa climate is conditioned by both NAO (Northwestern) and ENSO (Northeastern) is relevant for this study (*Hasanean, 2001*). Furthermore in two recent studies *García-Herrera et al. (2001)* and *Gallego et al. (2001)* showed that the climate of the Canary Islands is modulated by both dynamical modes. So if NAO and ENSO have any contribution in the interannual variability of the annual cycle of temperature this has to be reflected in Northern Africa.

2. DATA AND METHOD

This study differs from previous studies both in data and methodology. Instead of using monthly-mean temperature observations and estimating the amplitude and phase of the annual harmonic, we use daily data, fit these data to harmonic functions and from those functions we estimate both amplitude and inflection point. This point is an indicator of the spring onset.

2.1. Data

Daily-mean 2 meters air temperature data from NCAR-NCEP data (*Kalnay et al., 1996*), on a 1.9° by 1.9° grid box basis are used in this analysis (http://www.cru.uea.ac.uk /cru/data/ncep). The considered region ranges from 11.25°W to 39.375°E longitude and from 29.53°N to 37.14°N latitude (Fig. 1). The higher resolution than previous studies (5° × 5°) tries to capture as many as possible regional differences. Additionally, three instrumental series extracted from the European Climate Assessment & Dataset (ECA&D) (*Tank et al., 2002*) (http://www.knmi.nl/samenw/eca/htmls/index5.html) were used to check our results obtained with the reanalyzed data against results obtained with real data. The stations selected were Malaga airport (Spain) - 36.40ºN–4.29ºW; Alger-Dar el Beida (Algeria) - 36.43ºN–3.15ºE; and Heraklion (Greece) - 35.20ºN–25.11ºE- (see Fig. 1).

2.2. Method

We fit daily data for each grid point series and for each year to the following expression with a significant level of 0.05

$$y = a + b \sin\left(\frac{2\pi}{d} x + c\right).$$

This method is similar to that described by *Wilks (1995)* and used by *Wallace and Osborn (2002)* in which the amplitude and phase of the annual harmonic are diagnosed using a least-squares regression based on this function, being y temperature, x the time, d the period, b the amplitude and c the phase of that particular harmonic. In our analysis x varies from 1 to 365 (daily data) and in *Wallace and Osborn (2002)* varies from 1 to 12 (monthly data). The first 365 days of every year were used for the analysis, not considering December 31st for the adjustment in the leap years. In this way, possible problems related with artificial trends are avoided, though a possible, but weak, 4 years cycle may be induced in the final series. We have performed an iterative Levenberg-Marquardt least-squares fit to our function, adjusting the number of iterations to obtain a significant level of 0.05. Then, with the results of the adjustment, we calculate the first inflection point, as indicators of spring onset, and amplitude. We also followed the method used by *Wallace and Osborn (2002)* and we compare their results with those from our method. All grid points in the reanalysis and the three instrumental data were fitted using this method.

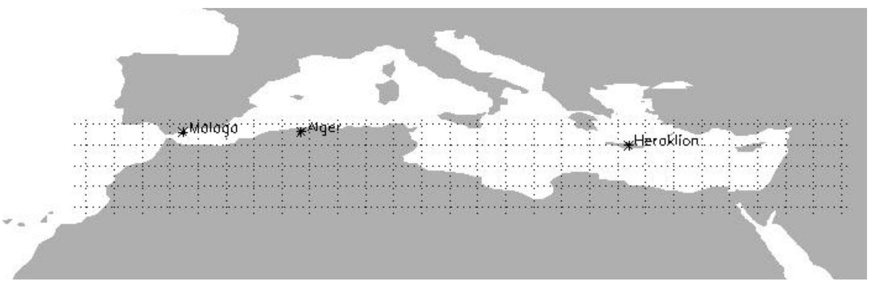

Fig 1. Area used in the analysis and location of three observatories with instrumental series.

3. RESULTS AND DISCUSSION

An illustrative example of the adjustment is shown in Fig. 2a for the grid point 37.1ºN, 15.0ºE and for 1982. The line corresponds to the adjustment where the confidence limit is 95%. It is used for all grid points to allow comparisons. In general terms, the adjustment was good as shown in the example. With the amplitude and the first inflection point for every year we built two temporal series for each grid point. Fig. 2b displays these two series for our example grid point.

a)

b)

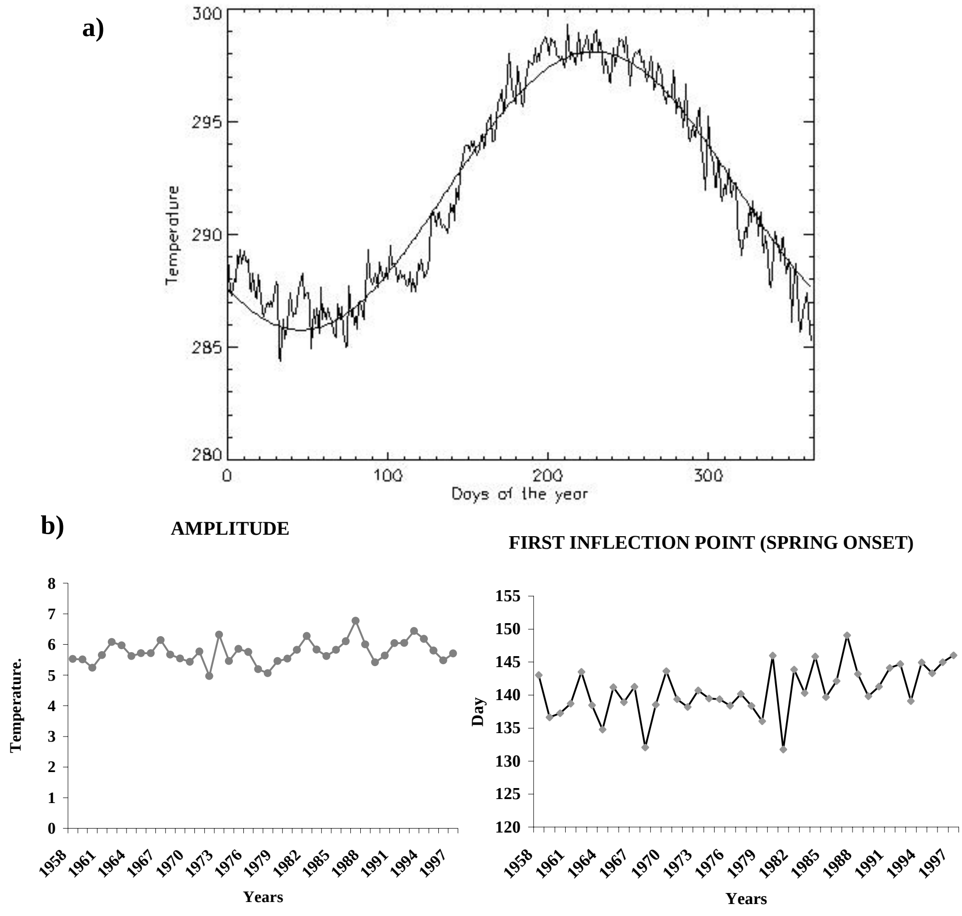

Fig. 2. **a)** Adjustment of the annual cycle for the grid point 37.1ºN, 15.0ºE and for 1982, **b)** temporal series of the amplitude (left) and the first inflection point (right) for the grid point 37.1ºN, 15.0ºE.

Additionally, we have compared the amplitude and first inflection point series of the each instrumental series with the corresponding series of the closest grid point. Pearson correlation coefficients between all the corresponding resulted significant at a 99% level. For the three cases, correlation coefficients were higher between first inflection point series than between amplitude series. The highest coefficient was obtained for Heraklion first inflection point series (0.88) and for both Alger series (0.84 for the first inflection point and 0.82 for amplitude), while Malaga Airport - with more missing data in its series - has a correlation coefficient for the first inflection point of 0.68.

As expected from the different specific heat between ocean and continents, the more continental is an area, the higher its annual average cycle amplitude (the first upper panel in Fig. 3) and the sooner the first inflection point is reached (the first upper panel in Fig. 4). So there is a difference of about 8°C in the amplitude and about 50 days in the first inflection point between central Northern Africa and the Atlantic coast. A similar pattern, though not so intense, occurs between continental and marine areas in the Eastern Mediterranean Sea. The spatial structure of the variance is analogous for the first inflection point, although opposite to that of the amplitude (the second upper panels in Figs. 3 and 4, high values in panels of Fig. 3 correspond to low ones in the corresponding panels of Fig. 4). A correlation analysis between NAO, SOI and NIÑO3 index vs. the amplitude and the first inflection point was done to check the influence of these phenomena in Northern Africa

To avoid the effects of spatial interdependence that may appear between neighbouring grid points when cross-correlation are computed, we have determined the statistical field, or global, 95% significance level through the use of a Monte Carlo simulation (*Livezey and Chen, 1993*). The correlations have been computed again replacing the NAO, SO and NIÑO3 indices by a Gaussian noise, and they have been tested for significance at the 95% level. This process was repeated with different random inputs and results were plotted as a percent histogram of statistically significant points. The threshold fraction of the 5% tail from the histogram is the limit above which the tested maps showed field significance.

As hypothesized, both ENSO and NAO have imprints in the annual cycle of temperature over Northern Africa. When NAO is in its positive phase - negative phase - there is a significant positive – negative - increase of the annual cycle amplitude over Algerian and Eastern Mediterranean coasts (fourth panel in Fig. 3), although there is not signal in the spring onset (fourth panel in Fig. 4). According to the results of the Monte Carlo test, these correlations are not spatially significant. During positive phases of ENSO the amplitude is much higher over the Atlantic coasts and the spring starts later than usual. On the other hand, over middle Northern Africa the amplitude is lower and the spring onset occurs anomalously soon. Imprints of opposite signs occur during negative ENSO phases (lower panels in Figs. 3 and 4). In this case, the correlations are spatially significant after being checked against the results of the Monte Carlo test.

In the previous work of *Wallace and Osborn (2002)* it was found that, in both simulated and observed time series, the NH shows a decline in amplitude being this decline higher over Russia. Over Northern Africa, they found a light decrease over the Atlantic coast and a light increment over the Eastern Mediterranean. These results are coincident with trends calculated in this study (third panels in Figs. 3 and 4). Considering the good agreement between observed and simulated data, these light variations could be

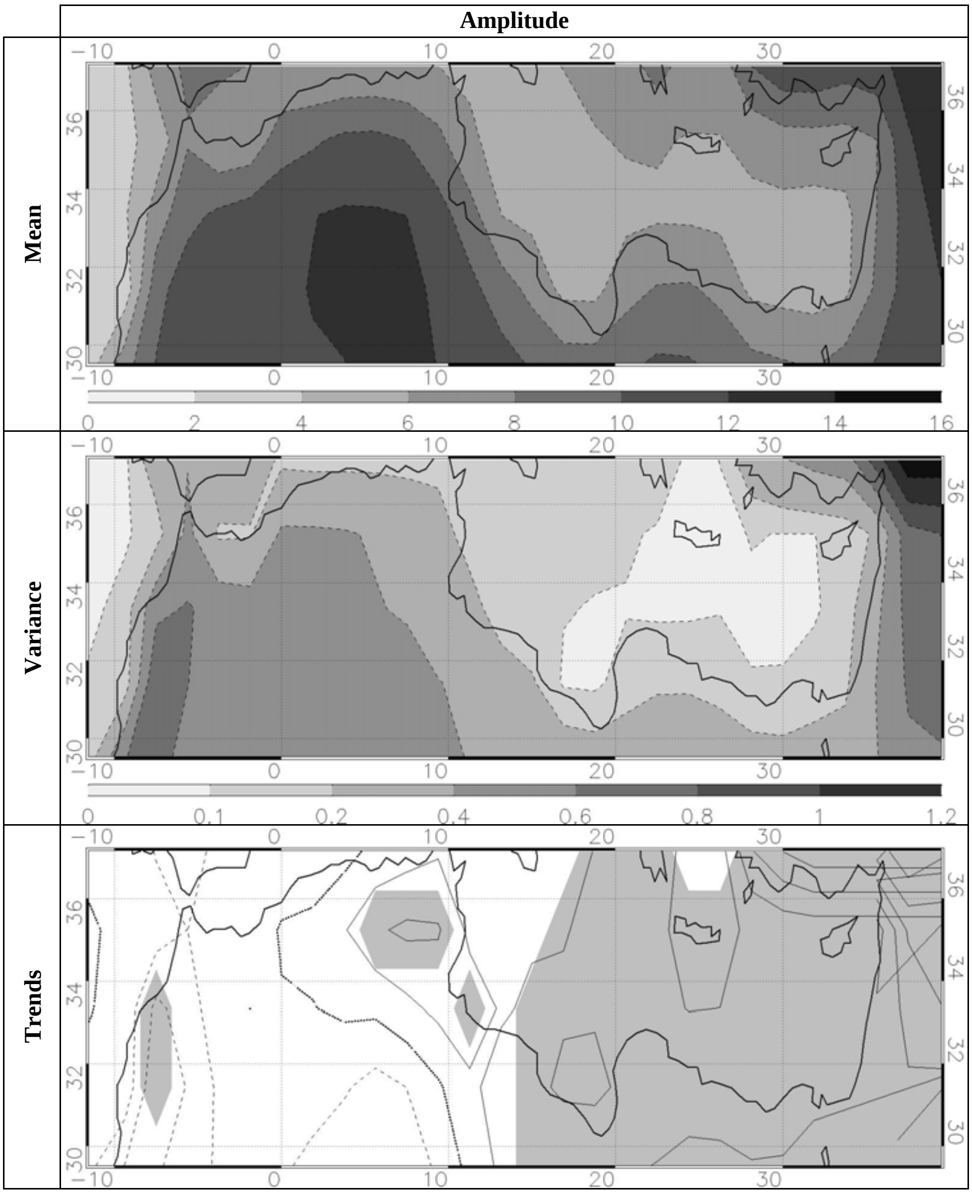

Fig. 3. Means, variances and trends for the amplitude. Shaded areas correspond to significant correlation (95% significant level). Distance between isopleths is 0.01°C/year for trends and 0.1 for correlations (being dashed lines the negative values, solid lines positive values and dotted lines the 0 line).

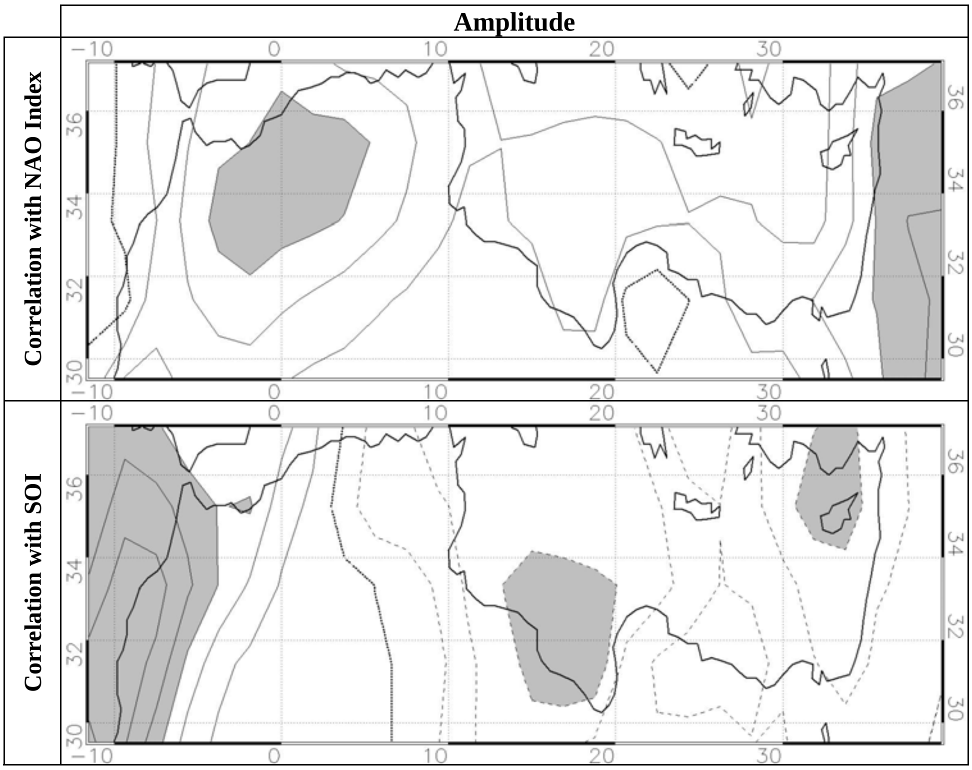

Fig. 3. Continuation. Correlation of the amplitude with with NAO and SOI. Shaded areas correspond to significant correlation (95% significant level). Distance between isopleths is 0.01°C/year for trends and 0.1 for correlations (being dashed lines the negative values, solid lines positive values and dotted lines the 0 line).

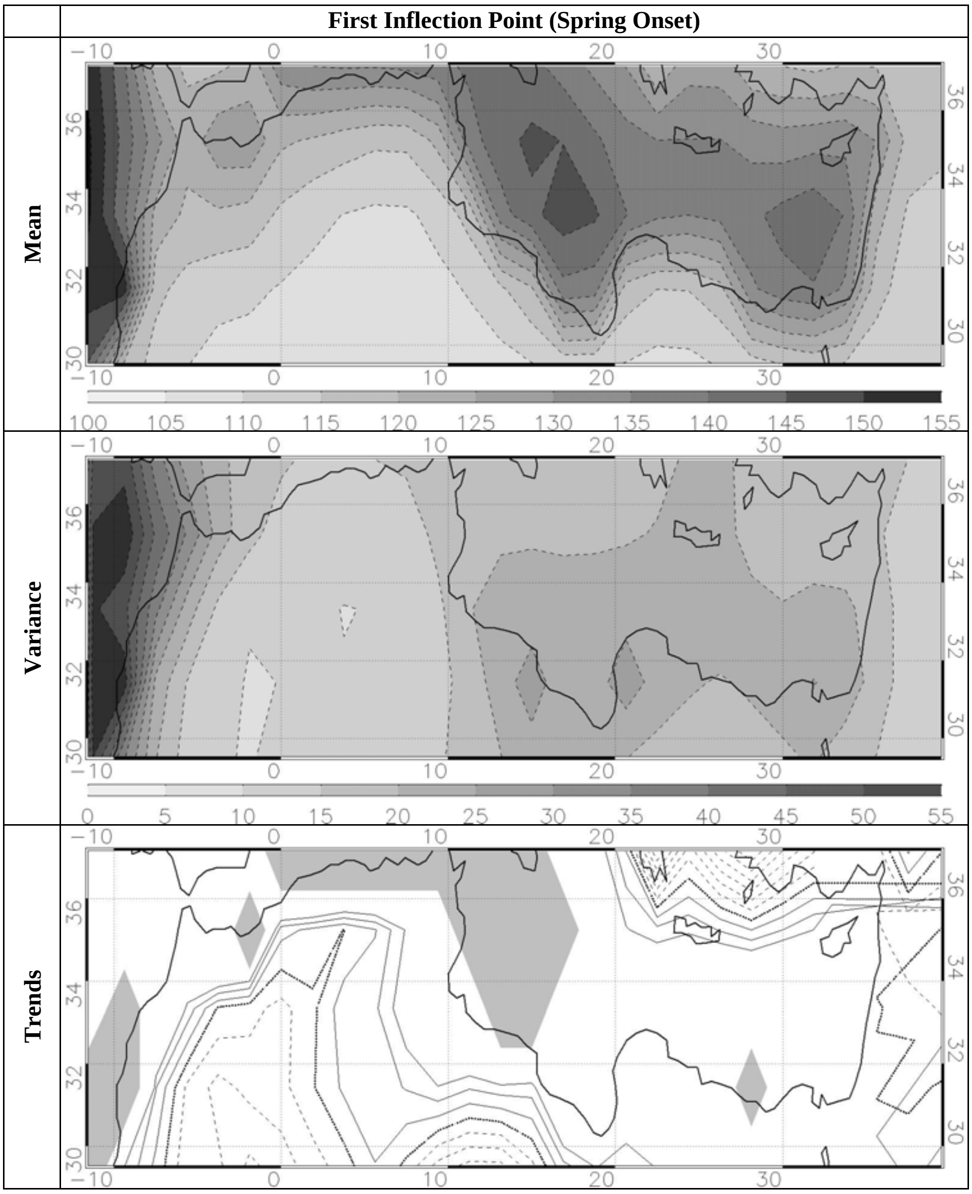

Fig. 4. Means, variances and trends for the first inflection point. Shaded areas correspond to significant correlation (95% significant level). Distance between isopleths is 0.03 days/year for trends and 0.1 for correlations (being dashed lines the negative values, solid lines positive values and dotted lines the 0 line).

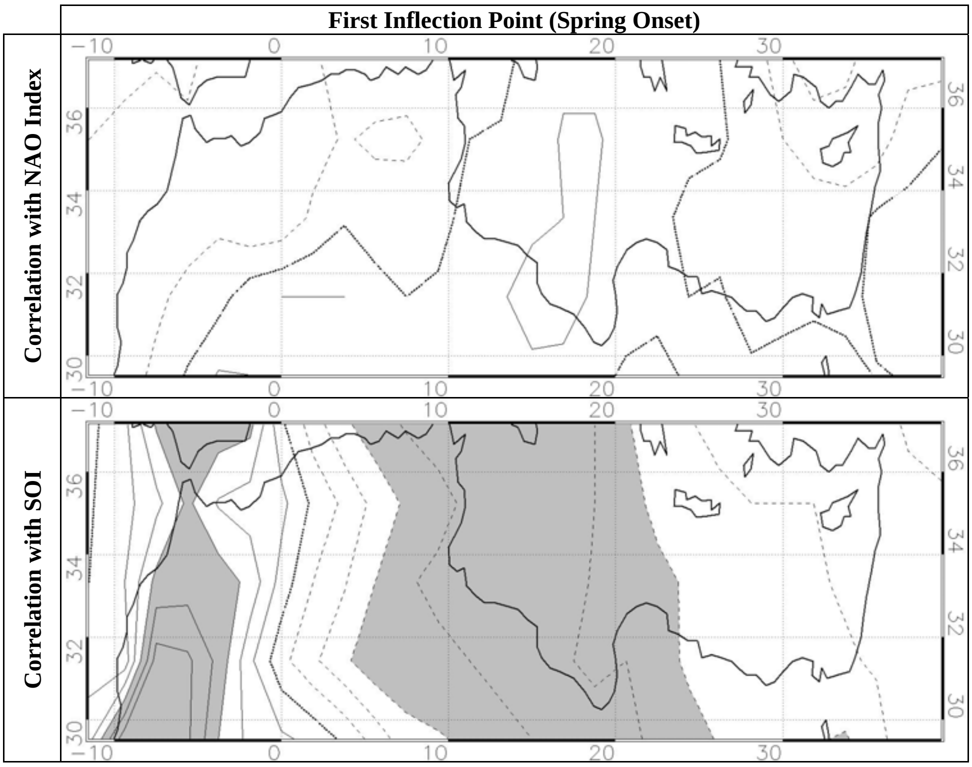

Fig. 4. **Continuation.** Correlation of the first inflection point with NAO and SOI. Shaded areas correspond to significant correlation (95% significant level). Distance between isopleths is 0.03 days/year for trends and 0.1 for correlations (being dashed lines the negative values, solid lines positive values and dotted lines the 0 line).

representative of a real physical mechanism, the main candidates should be the greenhouse gas signal expressed by mechanisms present in models or the result of internal variability, such as the winter North Atlantic Oscillation that has experimented a positive trend during the last decades. On the other hand the light decrease of the phase over the Atlantic coast of Northern Africa found by *Wallace and Osborn (2002)* is in good agreement with correlations with SOI found in this study and the strong ENSO events that happened in the last four decades (middle panels in Figs. 3 and 4). As well, *Wallace and Osborn (2002)* detected a light increase over middle Northern Africa that we do not detect.

Using daily data and the method employed by *Wallace and Osborn (2002)*, the results are analogous.

4. CONCLUDING REMARKS

This study confirms that major atmospheric circulation modes both in tropics (ENSO) and extra-tropics (NAO) are able to influence significantly the amplitude and phase of the seasonal cycle and, consequently, that interannual trends found in amplitude and phase should not be considered as caused directly and/or exclusively by the effect of greenhouse gases. A possible application of our results is the use of proxies based on the seasonal cycle to reconstruct both ENSO and NAO indices in historical times, which maybe used instead of, or added to, other proxies more traditionally employed, like those based on maximum temperature or precipitation events (*Gimeno et al., 1998; García-Herrera et al., 2002*). These results have to be confirmed in other areas such as Eurasia, where the highest trends of amplitude and phases have been found and where NAO effects are stronger.

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