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SOI and NAO impacts on *Pinus pinaster* Ait. growth in Spanish forests

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Introduction

Global change provides an extraordinary research opportunity and challenges for dendroclimatologists and other scientists who investigate the natural variability in the Earth's system (Hughes 2002). Climate has been used as a source of explanation for changes in the size and state of the tree-ring and it should be used to predict future tree-ring growth (Hughes 2002). The North Atlantic Oscillation (NAO) is traditionally defined as the normalized pressure difference between the Azores and Iceland. The NAO pattern is most pronounced both, in intensity and area coverage, during the winter. This phenomena is considered to be the most important source of climate variability in Europe, northern Africa and eastern North America; affecting temperature, precipitation and atmospheric circulation (Hurrell 1995, Hurrel & van Loon 1997). The Southern Oscillation Index (SOI) refers to the pressure variation between Darwin (Australia) and Tahiti. This pressure variation defines the cyclic warming and cooling of the equatorial Pacific Ocean, commonly known as El Niño phenomena (Bjerknes 1966). The impact of the SOI is felt mainly in the Pacific, however, its effect seems to influence climatic variability on a global scale (Trenberth et al. 1998).

The NAO and SOI should be considered as the major sources of the inter-annual variability of weather and climate around the world (Hurrell 1995, Hurrell & van Loon 1997). Over the last five centuries the connection between the mean winter precipitation over the Mediterranean and the NAO has turned out to be stable, with highly negative correlations throughout the period (Cook et al. 2001). *Pinus pinaster* Ait. occurs naturally in the western Mediterranean Basin, in the northern rim (France, Italy, Portugal and Spain) and in the southern rim (Algeria, Morocco and Tunisia). It is a characteristic species of the Mediterranean forests and its main distribution area is across the Iberian Peninsula where it covers about 2.4 million hectares (Blanco et al. 1997). It is adapted to different environments and, consequently, shows a wide ecological variety of adaptations: it survives under high or low temperatures, under regular or variable rainfall as well as under sever droughts; it is also adapted to the extremely cold winter in the centre of the peninsula and to the mild temperature next to the Atlantic ocean coast (Blanco et al. 1997).

There are no previous studies made on the impact of the SOI and NAO indexes on conifers growing in the Iberian Peninsula. Because of many scientists arguing about both indexes global impact on the earth's surface, it could be an excellent opportunity to analyse the relationship between these indexes and the growth of woody species. The aim of this study was to analyze the relation between the *Pinus pinaster* 's tree-ring width and the NAO and SOI atmospheric indexes in Eastern Spain. This objective was addressed analyzing sixty trees cored at four different sites. Correlation analysis, bootstrapped response function and Kalman filter analysis were applied to study both, time-independent and time-independent growth responses to atmospheric indexes.

Material and Methods

Study sites and laboratory methods

Four sampling sites were selected In Central Spain. The sites were located between 920 and 1,437 m a.s.l. (Fig.1, Tab. 1).

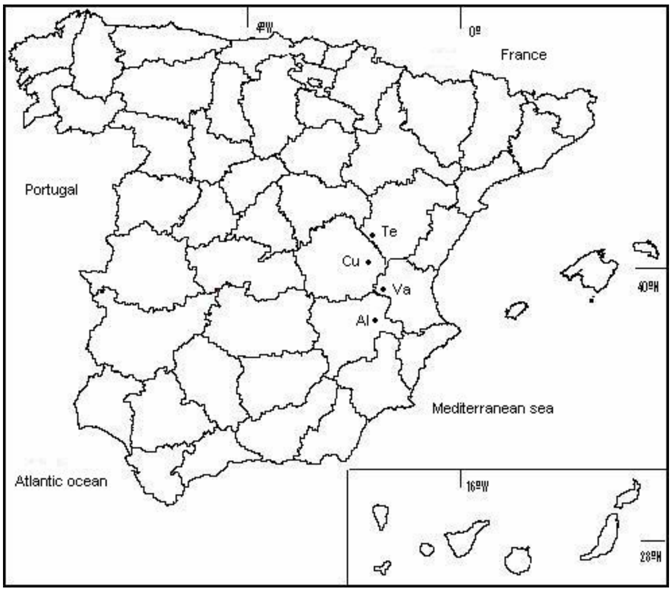

Figure 1: Geographical location of P. pinaster sampling sites in the Iberian Peninsula. The round points indicate the sampling sites. Sites codes: Te: Teruel; Cu: Cuenca; Va: Valencia; Al: Albacete.

The climate of the area is Mediterranean with sever droughts during the summer and precipitation from autumn to spring. Mediterranean Maritime pine grows on permeable soils, generally rich in organic matter, which have developed on calcareous or siliceous substrates. At each sampling site, in the summer of 2006, from fifteen dominant and co-dominant trees, two cores were extracted at a hight of 1.30 meter. Cores were polished and subsequently dated under a binocular microscope following standard dendrochronological techniques (Stokes & Smiley 1968). Sections were scanned at high resolution (2,000 dpi) with an Epson Expression 1640 XL scanner with a 0.01 mm accuracy. Tree-rings were measured using WinDENDRO© (Regent Instruments).

Statistical analysis

The NAO and SOI values were obtained from www.cru.uea.ac.uk/cru/data/nao.htm and www.cru.uea.ac.uk/cru/data/soi.htm (Jones et al. 1997). The COFECHA program 6.06P version (Grissino-Mayer 2001 available at: www.ltrr.arizona.edu) was applied to assess the data accuracy. This program calculates the correlation indices between the ring width series and also identifies errors such as missing or false rings. To eliminate the growth biological tendency and to minimise growth variation which was not present in all trees (Fritts 1976), the ARSTAN program, 2.07 version (Cook & Holmes 1984 available at: www.ltrr.arizona.edu) was used. To obtain a master chronology at each study site, the standardised series were averaged. These temporal series or master chronologies expressed the annual variations in radial growth of *P. pinaster* at each sampling place. The quality of the chronologies was evaluated using the mean sensitivity (MS) (Schweingruber 1996), the signal-to-noise ratio (SNR) (Fritts & Swetnam 1989) and the expressed population signal (EPS) (Wigley et al. 1984). A chronology is considered to be confident with a higher than 0.85 EPS value. The common growth signal between residual chronologies was analysed using the Pearson correlation coefficient (Sokal & Rohlf 1995).

To determine the climatic variables that control the growth of *Pinus pinaster*, atmospheric indexes were compared with residual chronologies from June previous to the growing season to September of the current growth year during the period 1950-2005. The PRECON program version 5.17 (Fritts 1999 available at: www.ltrr.arizona.edu) was used. This is a statistical model for analysing the tree-ring response to variations in climate using a stepwise multiple regression analysis. The coefficients are considered significant at a 95% level of confidence. The program also includes a bootstrapped response function to improve the statistical significance of the regression coefficient (p <0.05). In this analysis 999 interactions were made. To analyse the time dependent relationship between these atmospheric indexes and radial growth, Kalman filter analysis was applied (Visser & Molenar 1988).

Results

An evaluation of climate atmospheric indexes impact on radial growth of Mediterranean Maritime pines has been carried out. This evaluation was based on a dendrochronological analysis of dominant and co-dominant trees in four stands in Eastern Spain.

The descriptive statistic of all the chronologies showed that the mean sensitivity varied from 0.2571 to 0.3779, and the standard deviation varied from 0.2555 to 0.3179, according to the sampling site. The SNR fluctuated from 29.087 to 68.444, and the EPS values varied from 0.967 to 0.986. The total period covered by the chronologies varied from 120 in the shortest chronologies, to 162 years in the longest ones (Tab. 1).

Table 1: Coordinates, altitude, basal area (BA) and descriptive statistic of the four Pinus pinaster chronologies in Eastern Spain. SD: standard deviation; MS: mean sensibility; SNR: Signal to noise ratio; EPS: Expressed population signal. Te: Teruel; Cu: Cuenca; Va: Valencia; Al: Albacete.

	Te	**Cu**	**Va**	**Al**
UTM_X	639753	638858	648053	645583
UTM_Y	4464496	4467569	4411314	4411593
Altitud (m)	1437	1364	970	1090
BA($m^2.ha^{-1}$)	40.17	45.73	36.66	34.74
Time span	1844-2005	1847-2005	1879-2005	1886-2005
Core number	26	29	26	30
Ring number	3757	4128	2723	3043
Age range	124-162	124-158	72-127	72-120
SD	0.2589	0.3179	0.2555	0.2764
MS	0.2992	0.3708	0.2571	0.2978
SNR	29.087	68.444	38.528	36.254
EPS	0.967	0.986	0.975	0.973
Variance in first eigenvector	54.85	71.41	62.78	59.62
Mean correlation among trees	0.528	0.702	0.606	0.573

The four chronologies showed high SNR (over 29.087) and EPS (over 0.967), and the percentage of the variance accounted for the first eigenvector (over 54.85) reflected a strong common signal related to climatic-environmental factors. The Pearson correlation coefficient between all residual chronologies varied from 0.37 to 0.76 in the 1887-2005 common growth period (DF = 111 and $p^* < 0.05$). The association between radial growth and monthly climatic atmospheric indexes is shown in figure 2. The total variance explained by atmospheric indexes varied from 8.95 to 37.46%.

The total variance explained by the NAO and SOI indexes is higher in the sites at higher positions (chronologies Te and Cu). In these places there is a significant negative association between the NAO index and growth during January and March (site Te) and December and March (site Cu), but only March is significant in the bootstrapped analysis. Only one place showed a positive association with NAO values during September prior to the growing season (Site Al), but this association was not significant in the bootstrapped analysis. The association with the SOI was positive in all the analysed sites, but it was only significant, in the correlation coefficient and the in the bootstrapped response function, in place Cu. Only site Al showed a negative association with the SOI, shown by the bootstrap coefficient during March previous to the growing season.

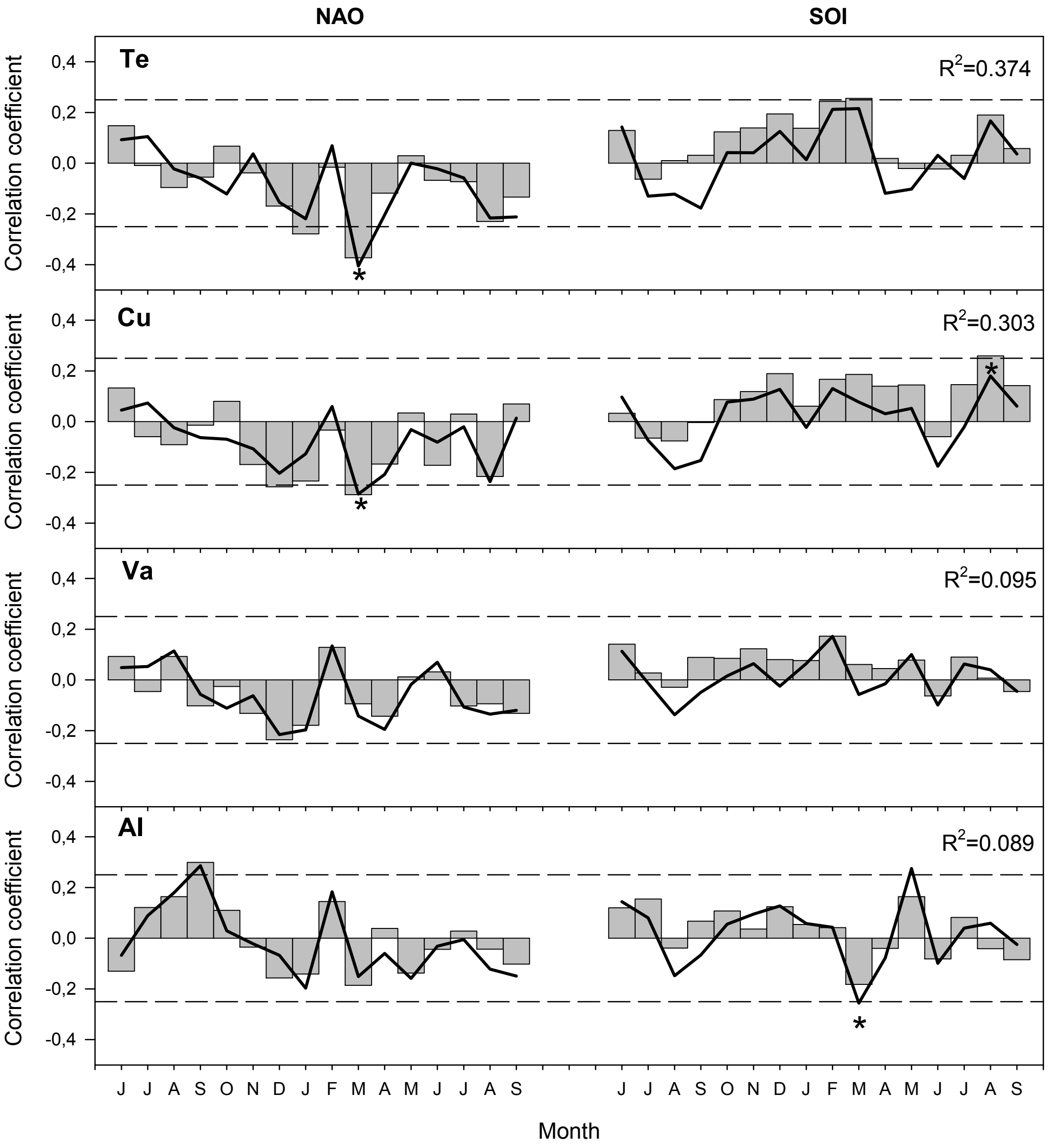

Figure 2: Regression coefficients (bars) and bootstrapped response function (lines) which relate the effect of climatic atmospheric indexes and growth of Pinus pinaster during the 1950-2005 period. The analysed period is from June to the previous growing season to September of the current growing season. Bars higher than the dashed lines show significant coefficient at the 0.05 level. Asterisks point the months where the bootstrapped response function coefficients are significant at the 0.05 level. R^2 values show the total variance explained by both indexes. Sites codes: Te: Teruel; Cu: Cuenca; Va: Valencia; Al: Albacete

The Kalman filter showed that no place showed a changing association through time with NAO index. Only place Te showed a changing association with SOI, statistically significant in February, from 1982 to 1987. This significant association was coincident with the strongest El Niño phenomena recorded during the last century.

Discussion

It is difficult to find a simple linear correlation between radial growth and atmospheric indexes because their global effects and their impact on regional climatic variables are not yet completely understood.

In these results, the total variance explained by NAO and SOI indexes suggested that the signal is weak if it is compared with regional climatic variables. However, the negative correlation with NAO during winter in two sites, and the changing effect of SOI index through time in one site, offer new information about the association between atmospheric indexes and coniferous species growing in the Iberian Peninsula.

Although atmospheric indexes explain less variability than other regional climatic variables, these results emphasis that these indexes effects could be recorded on tree-ring and they could have a sensible effect in growth of woody species, even if their action centres are located too far away from the analysed sites.

Previous studies have determined an opposite relation between winter NAO index and precipitation on the Iberian Peninsula (Esteban Parra et al.1998) and in this study two sites showed a negative winter correlation with the NAO index, consequently, these results suggest that these negative relation between NAO and growth could be associated with a moisture availability that could affect growth. Also, NAO effect is related to altitudinal position: the highest sites showed a significant relation with NAO during winter but there was no association with NAO values at the lowest analysed sites.

The association between growth and the NAO index was different from *Pinus sylvestris*_across Northern Fennoscandia where this species had a positive correlation between early winter NAO indexes previous to the growing season and late spring NAO (Macias et al. 2004). In our study, only one place showed a positive association with the NAO during the autumn previous to the growing season. The positive correlation these authors found in Fennoscandia between the NAO winter index and growth does not exist in Spanish Mediterranean Maritime pine forests at any sampling site. This difference could be explained by the fact that the effect of the NAO index on Northern Europe is opposite to the effect in Southern (Hurrel 1995).

In Spain, the relation between the SOI and plant growth has only been previously analysed on annual crops (Gimeno et al. 2002). As far as we know, there is no study focused on forest growth related to the SOI in our region. According to Trenberth et al. (1998) the SOI index mainly affects the Pacific area, but they consider that its effect might also influence climatic variability on a global scale. In this study a positive association was found between the index named above and growth in August in one of the highest sites, and negative in March in one of the lowest altitudinal position sites. Unfortunately, previous studies on the SOI effect in Spain are contradictory, as a consequence of that, future studies have to be made in order to understand better the opposite effect, according to the site and the changing impact through time. Modelling the impact of climate change on the distribution of species on a European scale under future climatic scenarios, Spain's environment will become unsuitable for *Pinus pinaster* by 2080 (Harrison et al. 2006). This would be coherent if growth were associated with precipitation, but the comprehensive general circulation models used for future climate projections leave us with an indeterminate picture of ENSO's future. Some observers predict more ENSO activity, others less, with the highly uncertain forecast consensus indicating little change (Cane 2005). Considering that this index shows a peculiar association with growth, which changes through time, future studies will have to be carried out.

Results can serve both, to understand climate/forest growth associations, and to determine which climatic variables can be useful for improving empirical models in order to help forest managers to adopt decisions in the future within the context of an extremely unpredictable climatic scenario.

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