CIHEAM
Options Méditerranéennes

Use of NAO index to improve drought forecasting in the Mediterranean area: application to Sicily region

Di Mauro G., Bonaccorso B., Cancelliere A., Rossi G.

in

López-Francos A. (ed.).
Drought management: scientific and technological innovations

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 80

2008
pages 311-19

Article available on line / Article disponible en ligne à l'adresse :

http://om.ciheam.org/article.php?IDPDF=800456

To cite this article / Pour citer cet article

Di Mauro G., Bonaccorso B., Cancelliere A., Rossi G. **Use of NAO index to improve drought forecasting in the Mediterranean area: application to Sicily region.** In : López-Francos A. (ed.). *Drought management: scientific and technological innovations.* Zaragoza : CIHEAM, 2008. p. 311-19 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 80)

CIHEAM

http://www.ciheam.org/
http://om.ciheam.org/

Use of NAO index to improve drought forecasting in the Mediterranean area: Application to Sicily region

G. Di Mauro, B. Bonaccorso, A. Cancelliere and G. Rossi
Department of Civil and Environmental Engineering, University of Catania,
Viale Andrea Doria 6, 95125 Catania, Italy

SUMMARY – Drought forecasting can potentially benefit from information related to large scale climatic indices like NAO (North Atlantic Oscillation), that exerts a strong influence on the European climate. The study aims to investigate the potential use of NAO to improve drought forecasting in the Mediterranean area. In particular the investigation focuses on Sicily region (Italy) through a preliminary correlation analysis oriented to assess the influence of NAO on Standardized Precipitation Index (SPI) series. Then a stochastic model able to estimate the transition probability among drought classes described by SPI with NAO as exogenous variable is developed. Results indicate that the inclusion of NAO as a predictor improves the forecast accuracy of the model.

Key words: Drought forecasting, SPI, NAO, stochastic approach.

RESUME – *"Utilisation de l'indice NAO pour améliorer la prévision de la sécheresse en Méditerranée : Application à la région de Sicile". La prévision de la sécheresse peut être potentiellement favorisée par les informations qui dérivent des indices climatiques comme le NAO (North Atlantic Oscillation), qui exerce une forte influence sur le climat européen. L'étude essaye d'examiner la possible utilisation du NAO pour améliorer la prévision de la sécheresse dans la Méditerranée. En particulier, cette recherche présente une analyse pour évaluer l'influence du NAO sur les séries du Standardized Precipitation Index (SPI) en Sicile (Italie méridionale). Donc, cette étude développe un modèle stochastique pour évaluer la probabilité de transition parmi les classes de sécheresse qui sont décrites par le SPI avec le NAO utilisé comme variable exogène. Les résultats finaux démontrent que l'inclusion du NAO améliore la précision du modèle développé.*

Mots-clés : *Prévision de la sécheresse, SPI, NAO, approche stochastique.*

Introduction

It is largely recognized that an effective mitigation of the most adverse drought impacts is possible, more than in the case of other extreme events such as floods, hurricanes, etc., due to the fact that drought consequences take a significant amount of time in order to be perceived by the socio-economic systems. Within this context, an effective monitoring and forecasting system, able to promptly warn of the onset of a drought and to follow its evolution in space and time, represents the prerequisite for a successful mitigation strategy (Rossi, 2003).

Several drought indices have been proposed for drought monitoring, among which the Standardized Precipitation Index (SPI) (McKee *et al.*, 1993) has probably found the most widespread application. Several authors have proposed methods to forecast or to assess the probable evolution of SPI (Moreira *et al.*, 2006; Cancelliere *et al.*, 2005; Bordi *et al.*, 2005). Recently, Cancelliere *et al.* (2007) have proposed a stochastic model to forecast SPI values at short-medium term, as well as to estimate transition probabilities of SPI classes corresponding to drought of different severities.

Despite such efforts, forecasting when a drought is likely to begin or to come to an end is still a difficult task (Cordery and McCall, 2000). Recently, important progress is being made in relation to the possibilities of using information provided by large-scale climatic indices, such as the North Atlantic Oscillation (NAO), as a support to drought forecasting. Influence of NAO index on precipitation in western Europe and the Mediterranean basin has been observed by several authors (Hurrell, 1995; Qian *et al.*, 2000, Goodess and Jones, 2002) Thus, including the information from such an index within a forecasting model, could potentially lead to an improved forecasting ability, as well as to a longer time horizon of forecasting.

The aim of the present paper is to assess whether considering a large scale climatic index as NAO leads to improvements in the estimation of drought classes transition probabilities in Sicily. In particular, a previously derived methodology that enables to estimate transition probabilities from a drought class of SPI in the present to another in the future (Cancelliere *et al.*, 2007) is extended here in order to include information provided by an exogenous variable such as NAO index. The proposed model enables to overcome the difficulties related to the relatively limited number of droughts generally observed in historical records.

First a preliminary correlation analysis between SPI series, computed on areal precipitation in Sicily, and NAO series is carried out. Then the model is applied with or without making use of NAO as exogenous variable and the statistical significance of the differences in the estimated transition probabilities either considering or not the NAO influence is assessed by means of Montecarlo analysis.

Data and methods

SPI series have been computed on areal monthly precipitation series from 1921 until 2003, obtained by applying Thiessen polygons method on 40 precipitation stations in Sicily (Cancelliere *et al.*, 2007). Since the present work focuses on forecasting drought conditions, in what follows the near normal and wet classes, generally adopted for monitoring also wet periods (e.g. NDMC, http://drought.unl.edu), have been grouped into one class termed "Non drought" (Table 1).

Table 1. Wet and drought period classification according to the SPI index

Index value	Class	Probability	ΔP	
$1.0<SPI<+\infty$	Wet	0.841-1.000	0.159	}Non drought
$-1.0<SPI<1.0$	Near normal	0.159-0.841	0.682	
$-1.5<SPI<-1.0$	Moderate drought	0.067-0.159	0.092	
$-2.0<SPI<-1.5$	Severe drought	0.023-0.067	0.044	
$-\infty<SPI<-2.0$	Extreme drought	0.000-0.023	0.023	

Regarding the NAO series, following Jones *et al.* (1997), it was decided to adopt the Gibraltar-Iceland NAO index developed by the Climatic Research Unit of the University of East Anglia, UK (http://gcmd.nasa.gov/records).

Let $Z_{\nu,\tau}$ indicate the SPI value at year ν and month τ = 1, 2, ... 12, for a given aggregation time scale of monthly precipitation. Also, let us indicate by C_i the generic drought class, for instance C_1=Extreme, C_2= Severe, C_3= Moderate, C_4=Non-drought. The probability that the SPI value after M months lies within a class C_M given that the SPI value at the current month τ lies within a class C_0, can be expressed, by definition of conditional probability, as:

$$P\left[Z_{\nu,\tau+M} \in C_M \middle| Z_{\nu,\tau} \in C_0\right] = \frac{\iint_{C_0,C_M} f_{Z_{\nu,\tau},Z_{\nu,\tau+M}}(t,s) \cdot dt \cdot ds}{\int_{C_0} f_{Z_{\nu,\tau}}(t) \cdot dt} \tag{1}$$

where $f_{Z_{\nu,\tau},Z_{\nu,\tau+M}}(\cdot)$ is the joint density function of $Z_{\nu,\tau}$ and $Z_{\nu,\tau+M}$, $f_{Z_{\nu,\tau}}(\cdot)$ is the marginal density function of $Z_{\nu,\tau}$, t and s are integration dummy variables, and the integrals are extended to the range of each drought class. For instance, if C_1=Extreme, the range will be (-∞, -2).

Since, by definition, SPI is marginally distributed as a standard normal variable, it is fair to assume the joint density function in eq. (1) to be bivariate normal (Cancelliere *et al.*, 2007). Thus, the computation of transition probabilities in eq. (1) requires the determination of the autocovariance at lag *M*. Such autocovariance can be estimated by computing the sample counterpart from the SPI series under investigation. Alternatively, under the hypothesis of uncorrelated and normally distributed monthly precipitation aggregated at various time scales *k*, it is possible to derive analytical expression of the autocovariance SPI, as a function of the statistics of the underlying precipitation (Cancelliere *et al.*, 2007).

The computation of the transition probabilities can be extended by including an exogenous variable in the model. Let $W_{\nu,\tau}$, indicate such an exogenous variable, with class limits C_{wi} and C_{ws}. Thus, the conditional probability given by eq. (1), becomes:

$$P\left[Z_{\nu,\tau+M} \in C_M \middle| Z_{\nu,\tau} \in C_o , W_{\nu,\tau} \in C_w\right] = \frac{\int_{C_{M_i}}^{C_{M_s}} \int_{C_{o_i}}^{C_{o_s}} \int_{C_{w_i}}^{C_{w_s}} f_{Z_{\nu,\tau+M}, Z_{\nu,\tau}, W_{\nu,\tau}} (t,s,u) \cdot dt \cdot ds \cdot du}{\int_{C_{oi}}^{C_{os}} \int_{C_{w_i}}^{C_{w_s}} f_{Z_{\nu,\tau}, W_{\nu,\tau}} (t,s) \cdot dt \cdot ds} \tag{2}$$

Assuming $W_{\nu,\tau}$ normally distributed, the joint distribution of $Z_{\nu,\tau+M}$, $Z_{\nu,\tau}$, $W_{\nu,\tau}$ is multivariate normal, and the probability density function at the numerator is given by:

$$f_{Z_{\nu,\tau+M}, Z_{\nu,\tau}, W_{\nu,\tau}} (t,s,z) = \frac{1}{2\pi|\Sigma|} \cdot \exp\left(-\frac{1}{2} \mathrm{X}^T \Sigma^{-1} \mathrm{X}\right) \tag{3}$$

with variance-covariance matrix:

$$\Sigma = \begin{bmatrix} 1 & \mathrm{cov}\left[Z_{\nu,\tau+M}, Z_{\nu,\tau}\right] & \mathrm{cov}\left[Z_{\nu,\tau+M}, W_{\nu,\tau}\right] \\ \mathrm{cov}\left[Z_{\nu,\tau}, Z_{\nu,\tau+M}\right] & 1 & \mathrm{cov}\left[Z_{\nu,\tau}, W_{\nu,\tau}\right] \\ \mathrm{cov}\left[W_{\nu,\tau}, Z_{\nu,\tau+M}\right] & \mathrm{cov}\left[W_{\nu,\tau}, Z_{\nu,\tau}\right] & \mathrm{var}\left[W_{\nu,\tau}\right] \end{bmatrix} \tag{4}$$

since var $[Z_{\nu,\tau}]$ = var $[Z_{\nu,\tau+M}]$ by definition. The bivariate density at the denominator is:

$$f_{Z_{\nu,\tau}, W_{\nu,\tau}} (t,s) = \frac{1}{2\pi|\Sigma_1|} \cdot \exp\left(-\frac{1}{2} \mathrm{X}^T \Sigma_1^{-1} \mathrm{X}\right) \tag{5}$$

with variance-covariance matrix Σ_1:

$$\Sigma_1 = \begin{bmatrix} 1 & \mathrm{cov}\left[Z_{\nu,\tau}, W_{\nu,\tau}\right] \\ \mathrm{cov}\left[Z_{\nu,\tau}, W_{\nu,\tau}\right] & \mathrm{var}\left[W_{\nu,\tau}\right] \end{bmatrix} \tag{6}$$

Integration of the triple and double integral of eq. (2) can be carried out numerically. Here, the algorithm MULNOR (Schervish, 1984) has been employed.

Results

In Fig. 1 linear correlation values between NAO series (averaged on 4 months – final month: January, February, March, April) and SPI series (k=4 months) simultaneous and shifted 1, 2 or 3 months ahead (different colour of bars) are shown, for three periods of observation of different length (i.e., 1923-2003, 1974-2003 and 1984-2003, corresponding to each plot). The correlation significantly increases as the observation period coincides with the last three or two decades. Besides, the highest values of correlation generally correspond to the periods ending in February and in March. The dashed line indicates the 5% significance bounds using *t*-Student's test and the bars over this line indicate significant values of correlation The null hypothesis of no correlation is rejected at α = 5%

significance level for most of the values, especially those corresponding to the last decades. In what follows, the 1974-2003 period (30 years) has been assumed as reference period.

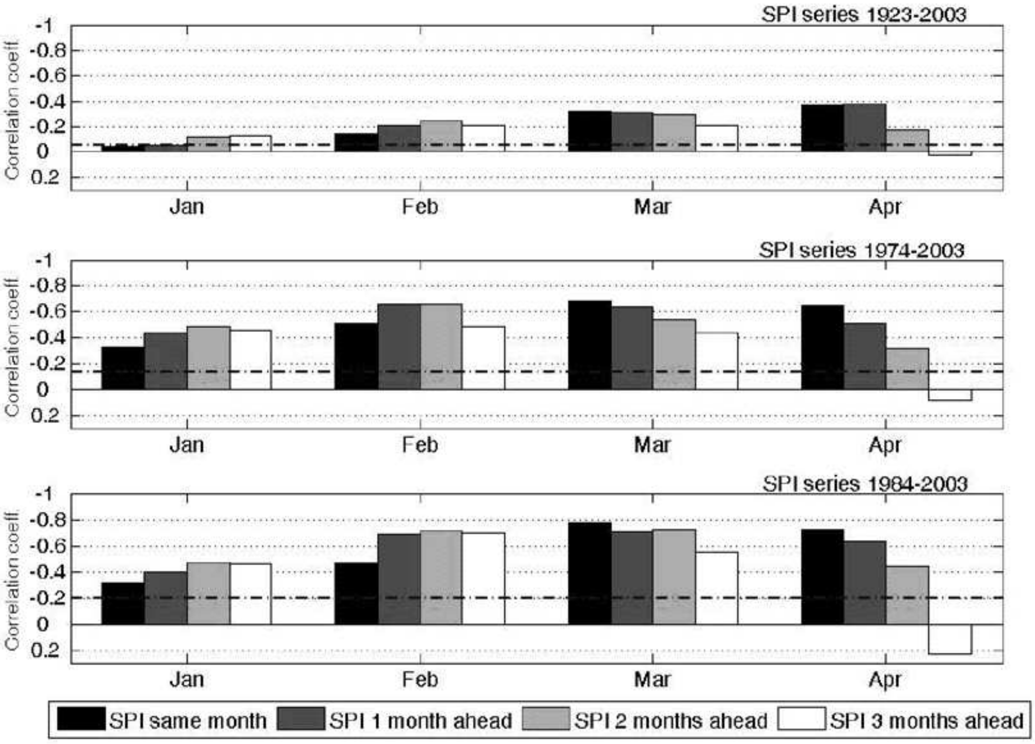

Fig. 1. Linear correlation coefficients between NAO series (averaged on 4 months ending in: January, February, March, April) and SPI series (k=4 months) simultaneous and shifted 1, 2 or 3 months ahead (different colour of bars), computed on different historic series.

In order to analyze the effect of the introduction of NAO index as exogenous variable within the model, the transition probabilities among drought classes defined by SPI (see Table 1) computed considering only the current SPI class, i.e. by means of eq. (1), have been compared with the corresponding ones computed by considering also NAO, namely by eq. (2). To this end, a classification of NAO index phases is required. Other authors (e.g. Muñoz-Díaz and Rodrigo, (2004) López-Moreno *et al.*, (2007)) adopted a three phases classification, based on mean plus or minus standard deviation bounds. Here, given the significant negative correlation observed between NAO and SPI series, the same classification of SPI, but changed in sign has been adopted, namely four classes whose limits (Cwi and Cws) in eq. (2) are:[-∞, 1], [1, 1.5], [1.5, 2], [2, +∞].

Different combinations of starting months, aggregation time scales and forecasting time horizons have been considered. Hereafter, for the sake of brevity, only results corresponding to an aggregation time scale and to an averaging time scale equal to 4 months for SPI and NAO series respectively, and by considering February as the current month and March as the future month of forecasting are presented in details.

Furthermore, in order to assess whether differences in transition probabilities computed by considering NAO as exogenous variable are due to statistical sampling or to an effective dependence between the index and SPI values in Sicily, confidence intervals of transition probabilities have been computed by generating, for each considered transition, 100 NAO series uncorrelated with the observed SPI series, and by computing the corresponding 100 transition probabilities by means of eq. (2). Generation of NAO series has been carried out through a simple white-noise model. Confidence intervals at 10% significance level are then estimated by considering the lower and upper 5% quantiles of such transition probabilities. Thus, if transition probabilities computed on observed series lie outside the confidence intervals, the null hypothesis of no dependence is rejected and the effect of NAO on drought transition probabilities in Sicily should be considered significant.

In Fig. 2, transition probabilities from different starting drought classes are shown. For each transition, probabilities computed by taking into account the current NAO class are depicted by coloured bars, with different colours according to the current NAO class. White bars correspond to transition probabilities computed without taking into account NAO, and therefore regardless of its current class. The lower and upper 5% quantiles of generated transition probabilities, under the hypothesis of no correlation between NAO and SPI, are indicated by black lines.

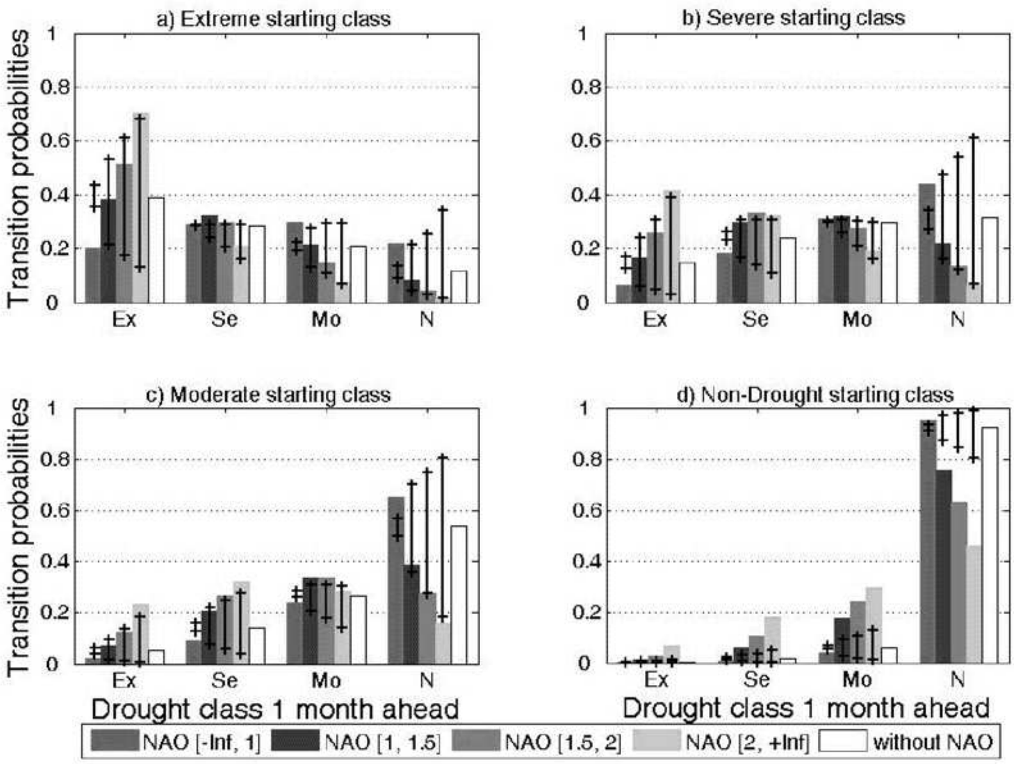

Fig. 2. Transition probabilities between drought classes with February as starting month, March as future month of forecasting for different starting classes a) Extreme, b) Severe, c) Moderate, d) Non-drought.

From the inspection of the figure, some interesting considerations can be drawn. First, when transitions related to persisting or worsening drought conditions (e.g. Ex/Ex, Se/Ex, Mo/Ex, Mo/Se, N/Ex, N/Se and N/Mo) are considered, the corresponding probabilities significantly increase as NAO index tends towards extremely positive values (i.e. NAO>2). On the other hand, considering drought conditions that turn to a less severe or to a Non drought (e.g. Ex/Se, Ex/Mo, Ex/N, Se/Mo, Se/N, Mo/N, N/N), leads to transition probabilities that decrease as NAO values increase.

Moreover, it can be observed that transitions probabilities are generally outside the confidence intervals computed under the no correlation hypothesis between NAO and SPI, which indicates that NAO exerts a significant influence on drought transitions in Sicily. In particular, when Non-drought is assumed as starting class (Figure 2d), transition probabilities toward all classes are outside the confidence intervals. In other cases, some probabilities lie within the confidence intervals, and therefore the influence of NAO does not appears significant.

Previous considerations are also confirmed by Table 2, where the most probable classes of transition are reported for all the considered NAO classes (eq. 2) and compared to the ones obtained by not considering NAO index (eq. 1). Results show that, while Non drought condition is the most probable future class when NAO is not considered (with the exception of the case of Extreme drought as starting class, which is likely to remain Extreme 1 month ahead), different outcomes are obtained when the effect of NAO is included in the model, with special reference to the cases of Severe and Moderate drought as starting classes and for NAO values respectively greater than 1 and 1.5. In addition, it is worth pointing out that, even when the two models yield the same most probable class, in many cases the introduction of NAO index generally yields to a significant difference in transition probabilities, as it can inferred from Fig. 2 for the cases: Se/N and Mo/N for the first NAO class (NAO<1), N/N for the second (1<NAO<1.5), the third (1.5<NAO<2) and the fourth class (NAO>2) and Ex/Ex for the fourth class (NAO>2).

Table 2. Most probable SPI classes of transition 1 month ahead for different NAO classes and without taking into account NAO index (starting month: February)

SPI at month τ	SPI at month τ+M				SPI at month τ+M
	NAO [$-\infty$, 1]	NAO [1, 1.5]	NAO [1.5, 2]	NAO [2, $+\infty$]	Without NAO
Ex	Mo	Ex	Ex	Ex	Ex
Se	N	Mo	Se	Ex	N
Mo	N	N	Mo	Se	N
N	N	N	N	N	N

Conclusions

Previous works have shown that NAO exerts a strong influence on Mediterranean climate. During the positive phases of NAO, for example, the North Atlantic westerlies shift northward and this, in turn, results in drier conditions over southern Europe, the Mediterranean Sea, and northern Africa.

In the paper an attempt is made to verify whether the use of a large scale climatic pattern, such as the NAO index, could improve drought forecasting, with special reference to Sicily region. A preliminary correlation analysis between NAO and SPI series in Sicily, considering different observation periods indicates that NAO series are significantly negative correlated with SPI series for winter months and especially on the last three decades. Then, the information provided by NAO index is included within a previously developed model which enables to estimate transition probabilities of SPI classes. The model indicates that NAO index can affect sensibly drought transitions in Sicily during the winter months. In particular, results indicate that transition probabilities from a drought class to another one more severe are mainly influenced by extremely positive values of NAO, for an aggregation scale of 4 months and a time horizon of 1 month.

The overall conclusion of the present work is that computation of drought transition probabilities can take advantage of analytical models, due to their ability to overcome difficulties related to a more traditional approach, based on a frequency computation and generally affected by large sampling variability. Also, analytical models enable to take into account information from exogenous variables exerting influence on the climate of the area under investigation, such as NAO, thus yielding to a more accurate forecast of drought class transitions.

Acknowledgements

The present research has been developed with the partial financial support of the EU Projects "Mediterranean drought preparedness and mitigation planning" (MEDROPLAN, EuropeAid MEDA, contract no. ME8/AIDCO/2001/0515/59770-P027) and of the Italian project MIUR PRIN 2005 "Previsione e mitigazione della siccità" (contract n. 20104030053).

References

Bordi, I., Fraedrich, K., Petitta, M. and Sutera, A. (2005). Methods for predicting drought occurrences. In: *Proc. of the 6th International Conference of the European Water Resources Association,* Menton, France, 7-10 September 2005.

Cancelliere, A., Di Mauro, G., Bonaccorso, B. and Rossi, G. (2005). Stochastic forecasting of Standardized Precipitation Index. In: *Proc. of XXXI IAHR Congress* "*Water Engineering for the future: Choice and Challenges*", Seoul, Korea, 11-16 September 2005, pp. 3252-3260.

Cancelliere, A., Di Mauro, G., Bonaccorso, B. and Rossi, G. (2007). Drought forecasting using the Standardized Precipitation Index. *Water Resources Management*, 21(5): 801-819.

Cordery, I. and McCall, M. (2000). A model for forecasting drought from teleconnections. *Water Resources Research*, 36: 763-768.

Goodess, C.M. and Jones, P.D. (2002). Links between circulation and changes in the characteristics of Iberian rainfall. *International Journal of Climatology*, 22: 1593-1615.

Hurrell, J.W. (1995). Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. *Science*, 7: 676-679.

Jones, P.D., Jonsson, T. and Wheeler, D. (1997). Extension of the North Atlanctic Oscillation using early instrumental pressure observations from Gibraltar and southwest Iceland. *International Journal of Climatology,* 17: 1433-1450.

López-Moreno, J.I., Beguería, S., Vicente-Serrano, S.M., García-Ruiz (2007). Influence of the North Atlantic Oscillation on water resources in central Iberia: Precipitation, streamflow anomalies, and reservoir management strategies. *Water Resources Research,* Vol. 43: W09411.

McKee, T.B., Doesken, N. J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In: *Proc. 8th Conference on Applied Climatology*, Anaheim, California, 17-22 January 1993, pp. 179-184.

Moreira, E.E., Paulo, A.A., Pereira, L.S. and Mexia, J.T. (2006). Analysis of SPI drought class transitions using loglinear models. *Journal of Hydrology*, 331(1-2): 349-359.

Muñoz-Díaz, D. and Rodrigo, F.S. (2004). Impacts of the North Atlantic Oscillation on the probability of dry and wet winters in Spain. *Climate Research,* 27: 33-43.

Qian, B., Corte-Real, J. and Xu, H. (2000). Is the North Atlantic Oscillation the most important atmospheric pattern for precipitation in Europe? *Journal of Geophysical Research*, 105: 11901-11910.

Rossi, G. (2003). Requisites for a drought watch system. In: G. Rossi *et al.* (eds), *Tools for Drought Mitigation in Mediterranean Regions*, pp. 147-157. Kluwer Academic Publishing, Dordrecht.

Schervish, M.J. (1984). Algorithm AS 195. Multivariate Normal Probabilities with Error Bound. *Applied Statistics*, 33(1): 81-94.