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Probabilistic forecasting of drought class transitions in Sicily (Italy) using Standardized Precipitation Index and North Atlantic Oscillation Index

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SUMMARY

Since the mid-90s the Standardized Precipitation Index (SPI) has found widespread use to monitor drought periods at different time scales. Recently, some efforts have been made to analyze the role of SPI for drought forecasting, as well as to estimate transition probabilities between SPI drought classes.

In the present paper probabilistic models for short and middle term forecasting of SPI drought class transition probabilities are presented and extended in order to include information provided by an exogenous variable, such as an index of large scale atmospheric circulation pattern like, for instance, the North Atlantic Oscillation index (NAO). In particular, the proposed models result from evaluating conditional probability of future SPI classes with respect to current SPI (and NAO) classes or current SPI (and NAO) values, under the hypothesis of multivariate normal distribution of the underlying joint variables.

SPI series are computed on average areal precipitation in Sicily region (Italy). As a significant negative correlation exists between NAO and SPI series in Sicily during recent decades, the proposed models are calibrated on the period from 1979 to 2008. Both SPI and NAO values are categorized in four classes. Transition probabilities to future SPI classes are evaluated based on SPI and NAO current classes or values and compared to the corresponding probabilities when NAO is neglected. Results indicate that drought transition probabilities in Sicily are generally affected by NAO index. In particular, transition probabilities related to persisting or worsening drought conditions significantly increase as NAO index tends toward extremely positive values. On the other hand transition probabilities to a less severe drought class decrease as NAO values increase.

Furthermore, application of a simple score approach to quantitatively assess the skill in forecasting of the proposed models shows that assessing transition probabilities to future SPI classes from current SPI and NAO values leads to better results than considering current classes.

1. Introduction

It is largely recognized that an effective mitigation of the most adverse drought impacts is possible by capitalizing on the usually significant delay between drought inception (i.e. meteorological drought) and the moment when its consequences are perceived by the water supply systems and the end-users (i.e. socio-economic impacts of drought). To this end, a drought monitoring and forecasting system, able to promptly warn against an incipient phenomenon and to follow its evolution in space and time, represents the prerequisite for a successful mitigation strategy (Rossi, 2003).

Many statistical and non statistical techniques have been proposed to forecast droughts (Bonaccorso et al., 2012 and references therein). Regardless of the specific methodology, a distinction can be made with reference to the objective of the forecast. On the one hand, the interest may lie in forecasting future values of the hydrometeorological variable or drought index under investigation. On the other hand, the objective may lie in determining transition probabilities from a given current drought class (expressed in terms of a drought severity variable or index) to another one in the future.

Several forecasting techniques have been proposed to assess the probable evolution of drought related hydrometeorological variables or drought indices, such as: time series modeling (Rao and Padmanabhan, 1984; Mishra and Desai, 2005; Cancelliere et al., 2007; Modarres, 2007; Fernandez et al., 2009; Durdu, 2010; Han et al., 2010), black-box models (Mishra and Desai,

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2006; Morid et al., 2007; Bacanli et al., 2009; Barua et al., 2012; Belayneh et al., 2014) and hybrid models (Kim and Valdes, 2003; Mishra et al., 2007; Farokhnia et al., 2011; Ozger et al., 2012).

With reference to the forecasting of drought class transition probabilities, most of the literature focuses on some drought indices, such as the Palmer index (Palmer, 1965) or the Standardized Precipitation Index (SPI) (McKee et al., 1993). In particular, since the early paper by Gabriel and Neumann (1962), Markov models have been largely applied to evaluate drought class transition probabilities. For instance, a non homogeneous Markov chain model has been applied by Lohani and Loganathan (1997) and Lohani et al. (1998) to drought classes identified by means of the Palmer index. Paulo and Pereira (2007) used homogeneous Markov models to predict drought class transitions probabilities of SPI at 12-month time scale. The lag-1 Markov hypothesis for SPI series has been questioned by Cancelliere et al. (2007), who derived approximate analytical expressions for SPI drought class transition probabilities by assuming a multivariate normal distribution for SPI time series. More specifically, in their study the auto-covariance matrix of SPI values is expressed as a function of the statistics of the underlying monthly precipitation process, assumed serially independent and normally distributed.

Besides Markov chains, other models have been employed to estimate drought class transition probabilities. Paulo et al. (2005) used 2-D loglinear models to fit drought class transitions matrices constructed for several sites in southern Portugal. Moreira et al. (2006) applied a loglinear modeling approach to investigate differences in SPI drought class transitions with reference to three different periods between 1932 and 1999, in order to detect possible trends in time evolution of droughts which could be related to climate change. Moreira et al. (2008) extended the work of Paulo et al. (2005) using the same drought classification and 3-D loglinear models to predict drought class transitions one month ahead, given the drought class for the last two months, which also allows for extending the prediction to two months ahead. Kavalieratou et al. (2012) used a 3-D loglinear models approach for short-term forecast

Table 1
Main studies investigating the link between winter NAO and drought conditions in Europe and the Mediterranean region.

Authors	Study area	Investigated variables	Methodology	Main findings
Cullen and deMenocal (2000)	Eastern Mediterranean	Winter station averaged normalized temperature and precipitation series and DJFMA average streamflow of the Euphrates and Tigris rivers	Pearson's correlation analysis	Significant correlation with NAO is detected, with temperature and precipitation series showing decreasing trends during the 1980s, when NAO was persistently positive
Wedgbrow et al. (2002)	England and Wales	Summer Palmer Drought Severity Index (PDSI) and monthly reconstructed river flows	Spearman Rank correlation analysis; Split sample (composite) analysis for monthly river flows; Coherence testing/ index of forecast potential (IFP)	Positive winter NAO phases are associated with negative PDSI in summer across the eastern parts of the British Isles. Winter NAO phases may also precede below-average autumn river flows in Southeastern England
Türkes and Erlat (2003)	Turkey	Annual and seasonal normalized precipitation anomaly series	Pearson's correlation coefficient *r*; Composite analysis	Annual and seasonal precipitation are mostly characterized by wetter than the long-term average conditions during negative NAO phase, whereas positive NAO responses mostly exhibit drier than the long-term average conditions, except in summer
Muñoz-Diaz and Rodrigo (2004)	Spain	Regionalized precipitation classified into three categories: drought, normal or abundant	Analysis of changes of the empirical distribution of precipitation anomalies corresponding to positive, neutral and negative NAO phases	Positive NAO has an influence on the probability of drought all over Spain, while negative NAO affects the probability of abundant rainfall over the western area
Van der Schrier et al. (2006)	Europe	Summer self calibrated PDSI (Sc-PDSI)	Spatial correlation analysis	The most positive correlations are found in Western Scotland and Southern Norway. The most negative correlations are found in large areas over Spain
Lopez-Moreno et al. (2007)	Tagus river basin (Central Iberia)	Regional monthly precipitation, river discharge, reservoir storage and reservoir release	Comparison between normalized monthly values of the hydrological variables during positive and negative NAO years with the monthly values during normal NAO years and years of opposite NAO sign	Positive NAO years result in reduced water availability, whereas negative NAO years result in increased water availability
Lopez-Moreno and Vicente-Serrano (2008)	Europe	Gridded Standardized Precipitation Index (SPI) at different time scales	Spatial and temporal analysis of regionalized SPI response to positive and negative NAO phases	SPI dry/wet conditions occur during the positive/negative NAO phases over Southern Europe, whereas the opposite pattern occurs in Northern Europe
Brandimarte et al. (2011)	Southern Italy and Nile Delta (Egypt)	Winter precipitation, river flow and temperature	Pearson's correlation analysis	Negative correlation is found in most of the southern Italy, while low positive correlation is found in Eastern Sicilia and Nile Delta
Vicente-Serrano et al. (2011)	Mediterranean Region	Standardized Precipitation Evapotranspiration Index (SPEI)	Composite analysis	Outstanding influence of positive and negative phases of winter NAO is ascertained on drought conditions during the succeeding months
Wang et al. (2011)	Europe	Sc-PDSI	Coupled Manifold Technique	NAO regime over the Mediterranean modulates summer climate over Europe through controlling winter precipitation. A positive phase of NAO tends to generate the possibility of a hot and dry summer or vice versa