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Analysis of changes in drought occurrence over the Mediterranean Basin using multiple time scales SPI index

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Motivation

Drought is a recurrent feature of climate variability and can produce **severe impacts** on a wide range of human activities. Today water management services in Europe are mainly focused on **saving water** and **improving its quality**, but climate and societal expected changes will **increase competition** between various users and economic sectors, while **water** becomes an increasingly **scarce resource** (The Leeuwarden Declaration, 2016).

There are an increasing numbers of studies on drought trend analysis using specifics indices over Mediterranean basin; some consider the whole Europe (e.g.: Lloyd-Hughes&Saunders, 2002, Sousa et al., 2011, Hoerling et al., 2012, Achcar et al.,2016).

There are several studies at national or regional scale, with a stronger research activity on north-western and central part of the basin (Spain, Italy and Greece).

Analysis are related to simple trends assessment (Buttafuoco et al., 2014**), to indices comparison (**Spinoni et al., 2015**) or on the relation between drought/precipitation trends and teleconnections, SST, temperature rise (**Sousa et al., 2011; Kingston et al., 2015; Hoerling et al., 2011; Vincente-Serrano et al., 2014; Mühlbauer et al., 2016; Mariotti&dell'Aquila, 2012; Xoplaki et al., 2012**) or weather types (**Russo et al., 2015; Vincente-Serrano et al., 2006**).**

Results of these studies are mostly in agreements, differences are due to:

- **Choice of drought indices**
- **Choice of the dataset: spatial and time scales; distribution and consistency of ground data**
- **Choice of the statistical methods to assess trends or to compare data**

Introduction

In this study the **Standardized Precipitation Index (SPI)** at multiple time scales (**3, 6, 12 months**) was used in order to evaluate **trends of drought events** in the **Mediterranean Basin**.
This index is particularly suitable both because it requires only precipitation data and the standardization of the values permits a comparison between areas climatically and geographically different.

DATASET

To obtain a spatiotemporal homogeneity of the SPI, the analysis was carried out using a gridded monthly precipitation dataset, covering an extended long time period.

CRU TS v.3.23 (Climatic Research Unit) - 0.5° grid resolution and a time span from 1901 to 2014.

TREND ANALYSIS OVERVIEW

1. we consider the arrival rate of drought events as a counting process of a **nonhomogeneous Poisson process** (NHPP), where the arrival rate do not remain constant through time
2. we consider the use of a special case of NHPP's: the **power law process** defined in Crow (1974)
3. χ^2 test of trend significance

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Trend analysis: which methodology?

In SPI trend-time analysis, a **moving window** is often used to count events in dryness classes. Then, a **linear regression** and its associated tests is typically adopted to evaluate the drought risk variation in time; among many, Naresh Kumar et al. (2012) and Jha, Sehgal, and Raghava (2011).

However, when a **truncation level** is imposed, time series of climatological extreme phenomena become **counting processes**.

Generally, the arrival rate of events of a counting process follows a **Poisson distribution** and, furthermore, if the arrival rate do not remain constant through time, then it follows a **nonhomogeneous Poisson process** (NHPP).

We consider the use of a special case of NHPP's: the **power law process** defined in Crow (1974).

The power law approach suggests the use of the χ^2 **test for time-trend analysis**. This approach is commonly used in risk evaluation, for example Ho (1996) uses it to evaluate volcanic eruptions time-trend or in lifetime analysis. Nevertheless, SPI applications in this theoretical framework already exist, for example Achcar, Coelho-Barros, and Souza (2016) use NHPP to identify change points in time series of droughts in Brazil.

Methodology (1)

Nonhomogeneous Poisson process (NHPP)

An homogeneous Poisson process has a **λ constant recurrence rate** for drought events. To analyze the increasing of those events we need to allow λ be a function of time: **λ(t)**. This nonhomogeneous Poisson process has ***mean function μ(t, Θ)***, with ***Θ*** vector of parameters and ***intensity function***:

$$\lambda(t,\Theta) = \frac{d}{dt}\mu(t,\Theta)$$

More specifically, let $N(t); t \geq 0$ be the number of droughts observed in ***(0,t]*** then ***μ(t, Θ)*** represents the expected number of events in ***(0,t]*** and ***λ(t, Θ)*** their associated recurrence rate.

Power law

Using a **power law** to define the ***mean* and *intensity* functions** they become:

$$\mu(t,\Theta) = \left(\frac{t}{\sigma}\right)^{\beta} \quad \beta,\sigma > 0$$

$$\lambda(t,\Theta) = \left(\frac{\beta}{\sigma}\right)\left(\frac{t}{\sigma}\right)^{\beta-1}$$

where $\Theta = c(\beta,\sigma)$

Now, we can model droughts by means of a power law process supposing that ***n>1*** violations from predetermined threshold are observed in ***(0,t]*** at time $0 < t_1 \leq t_2 \cdots \leq tn \leq t$ and we compute

$$S = \sum_{i=1}^{n} ln(t/t_i)$$

Methodology (2)

SPI time-trend test

From ***S***, Crow obtained **maximum likelihood estimators** of parameters:

mean (Crow, 1974) → $\hat{\beta} = n/S \qquad \hat{\sigma} = t/n^{1/\hat{\beta}}$

intensity (Crow, 1982) → $\hat{\lambda}(t) = (\hat{\beta}/\hat{\sigma})(t/\hat{\sigma})^{\hat{\beta}-1} = n\hat{\beta}/t$

In this framework, **the analysis of droughts time-trend is completely determined by *β***:

- ***β*>1,** the intensity of droughts is **increasing**
- ***β*<1**, **decreasing**
- ***β*=1** **constant**, i.e. the process is homogeneous Poisson.

Under the null hypothesis **H0: *β*=1**, the statistic is distributed as follows: $2S \sim \chi^2_{2n}$

The **test rejects the null hypothesis** if

$$\chi^2_{1-\alpha/2,2n} \leq 2S \leq \chi^2_{\alpha/2,2n}$$

where $\chi^2_{\alpha/2,2n}$ is the α-percentile of the χ^2 distribution with ***2n*** degrees of freedom.

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Results: trend test significance (1)

The χ^2 trend test is performed both at ***0.05*** and ***0.10*** error acceptance rates and the **null hypothesis** states that:

"**there is not a linear trend of drought episodes during the entire period 1901-2014**".

Technically, a significant results of this test means that there is no statistical evidence in favor of an absence of time-trend and the probability of error is 5(10) cases out of 100.

Selected seasons:

- SPI3 -> Feb, May, Aug, Nov
- SPI6 -> Feb, May
- SPI12 -> Aug

Three negative SPI classes:

- drought risk (SPI< -1)
- extremely dry (SPI< -2)
- extremely&severely dry (SPI< -1.5)

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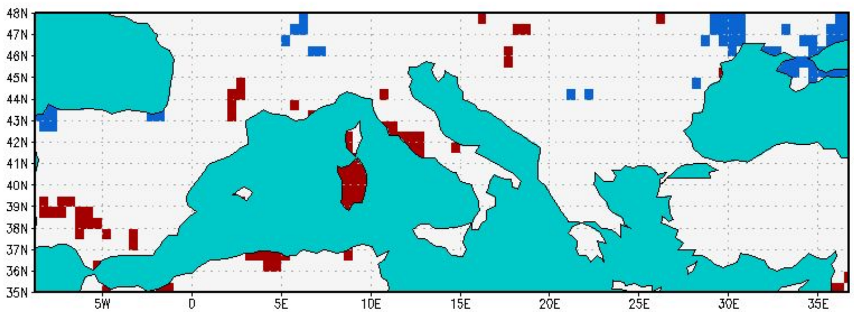
Results: trend test significance (2)

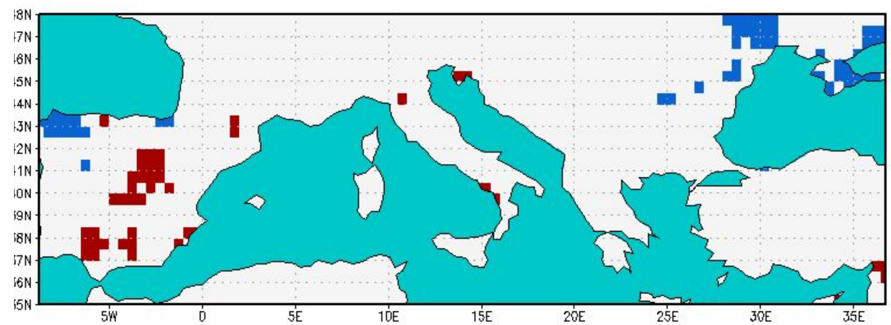
<u>SPI-12 for August</u> (yearly hydrological cycle)

- tendency of an **increasing drought risk** is present in several areas of Mediterranean basin: **Southern Spain**, **Sardinia**, **Tuscany**, a portion of **Algerian coast**.
- **Extreme drought** class reveals an increasing of episodes in **Central Spain** and **Campania region**.

Drought risk



Extreme

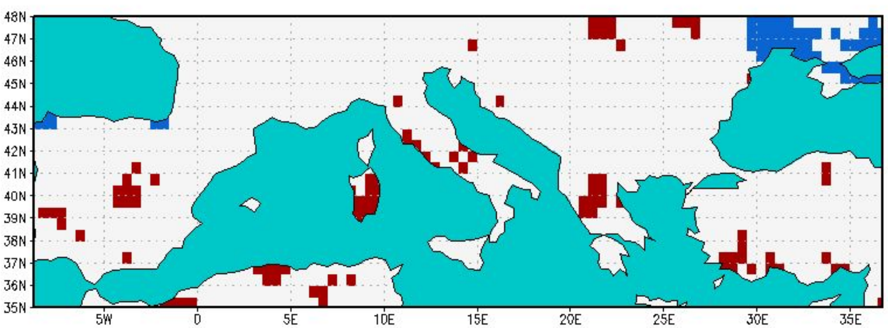


Results: trend test significance (3)

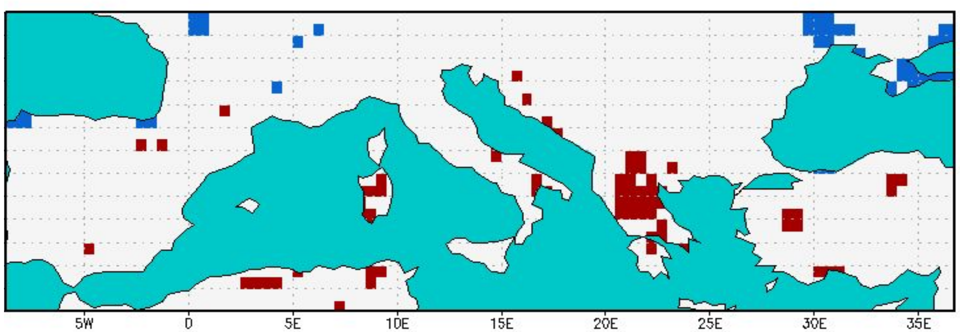
<u>SPI-6 for February</u> (Autumn-Winter precipitation deficit)

- increasing **drought risk** in **Central Italy**, **Macedonia** and **Turkey**
- **Extreme+Severe drought** class reveals an increasing of episodes in **Sardinia**, **Macedonia**, **Greece, Tunisia** and some part of **Algerian coast**

Drought risk



Extreme+Severe



Trend

Negative Positive

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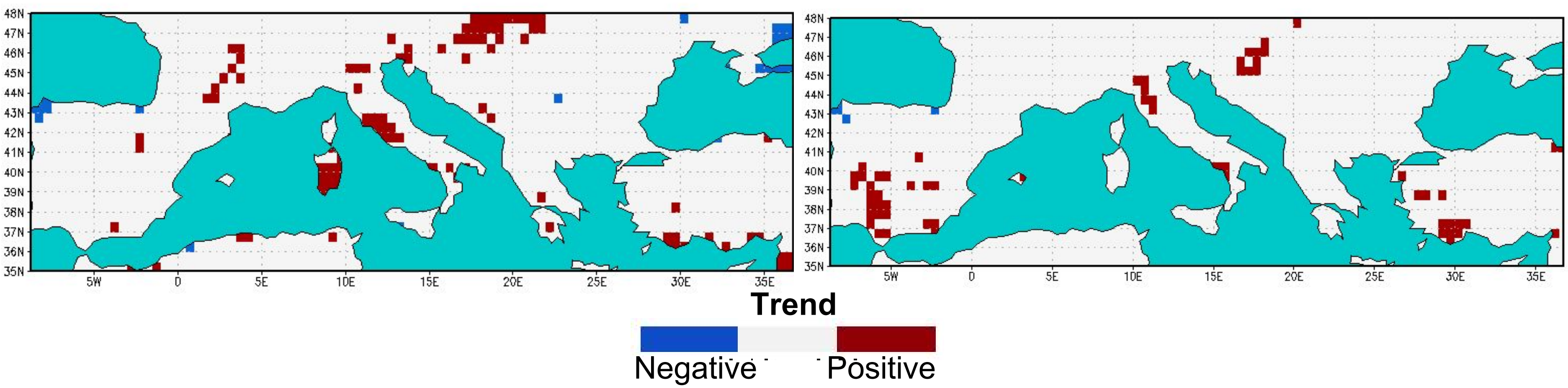
Results: trend test significance (4)

SPI-6 for May (Winter-Spring precipitation deficit)

- increasing **drought risk** in **Central Italy**, **Macedonia** and **Turkey.**
- **Extreme drought** class reveals that the increasing of episodes in **Central Spain** and **Campania region** at SPI-12 is mainly due to winter-spring deficit, other regions in **Northern Italy** and **South Turkey** are also involved

Drought risk *Extreme*

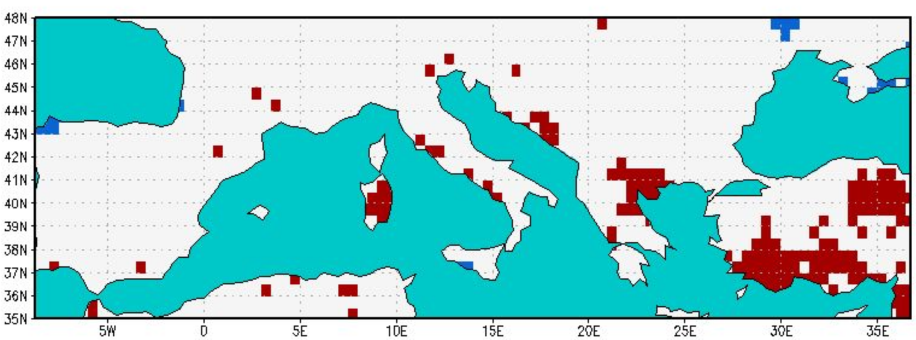


Results: trend test significance (5)

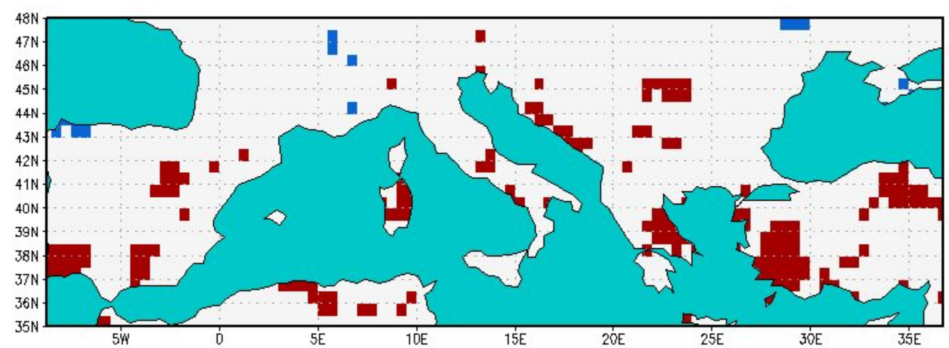
<u>SPI-3 for February</u> (Winter precipitation deficit)

- increasing **drought risk** in wide area of **Turkey**, **Macedonia** and **Sardinia** and **Libya**
- increasing of episodes in **Extreme+Severe class** in **Western and Southern Spain**, **Sardinia**, **Campania**, **Macedonia-Greece** and **Western Turkey**

Drought risk



Extreme+Severe



Trend

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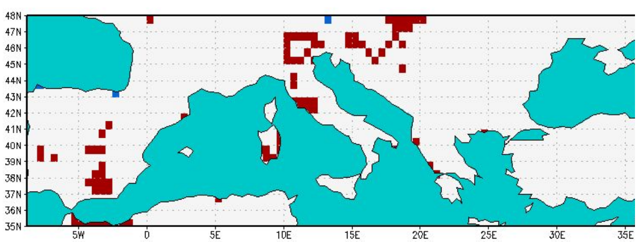
Results: trend test significance (6)

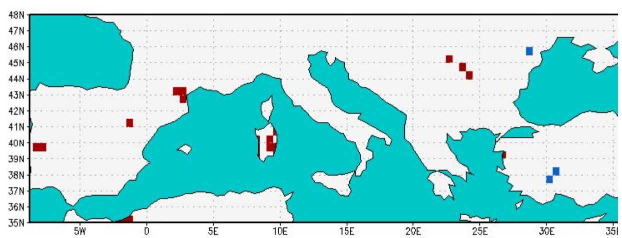
SPI-3 for May-August-November (Spring-Summer-Autumn precipitation deficit)

- increasing **drought risk** in **Morocco** and **small areas of Southern Spain**, **Sardinia**, **Tuscany** **during Spring**; and in **Sardinia**, **Tuscany** and **Macedonia** **during Autumn.**
- no evidence of episodes increasing in **Extreme class**

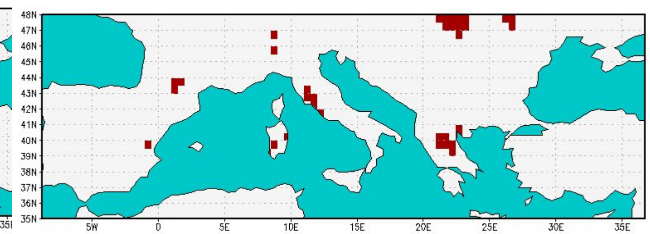
Spring Drought risk



Summer Drought risk



Autumn Drought risk



Trend

Negative Positive

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Discussion

This study investigates the existence of **linear trend of drought events** in the **Mediterranean basin** during the period **1901-2014**:

- ➔ the analysis of **August SPI-12** shows that the tendency of an increasing drought risk is present in **several parts of Mediterranean basin** and, particularly, an increasing of *Extreme* episodes in **Central Spain** and **Campania region**;

- ➔ the analysis of **SPI-6 (Feb and May)** reveals again the increasing of drought risk for **Central Spain** and **Campania region** and it extends this results to **Macedonia**, **Greece** and some part of **South Turkey**;

- ➔ **SPI-3** index reproduces the drought risk due to **seasonal precipitation deficit**: February, May, August and November SPI-3 are for Winter, Spring, Summer and Autumn, respectively. The results show that **Winter** is the most involved in **increasing trend of droughts**.

In general, the extending of test error acceptance level to 0.10 does not give further information with respect to 0.05 level, except for few local cases.

These findings are similar to those shown in previous studies: Lloyd-Hughes&Saunders, 2002, Sousa et al., 2011, Hoerling et al., 2012.

The statistical robustness is here guaranteed by more simple assumptions.

Further developments

This approach could be adopted in order to:

- identifying change points in time series of droughts and analysing trend in associated sub-periods or epochs;
- Highlighting active atmospheric and oceanic forcing mechanisms during specific epochs.
- Improving the quality of climate services (in the water management sector) both at seasonal and at decadal time scale.

Thanks for your attention!

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In this study we used *R software* [R Core Team (2016)] and [Beguería and Vicente-Serrano (2013)] R package for SPI calculation.