

## DROUGHT ASSESSMENT USING THE RECONNAISSANCE DROUGHT INDEX (RDI) IN A SOUTHERN ITALY REGION

*G. Buttafuoco, T. Caloiero, I. Guagliardi, and N. Ricca*

National Research Council of Italy, Institute for Agricultural and Forest Systems in the Mediterranean (ISAFOM), Rende (Cosenza), Italy, [ilaria.guagliardi@isafom.cnr.it](mailto:ilaria.guagliardi@isafom.cnr.it).

**Abstract:** Drought is one of the most common natural events having a great negative impact on agriculture being associated with a deficit of water resources over large geographical areas. Drought severity is conventionally assessed by various drought indices, which depend on different types of data. Among them, the Reconnaissance Drought Index (RDI) exhibits significant advantages over the other indices in the calculation of the drought severity by using, simultaneously, the precipitation and the potential evapotranspiration cumulated on a reference time scale processing monthly, seasonal or annual data. The main objective of the study was to assess the drought severity in a southern Italy area (Calabria region) by using the RDI and to map its spatial distribution and uncertainty. Calculating RDI requires the availability of precipitation and temperature data covering the whole study area. Precipitation and temperature data can be treated as random variables and analyzed by geostatistical methods. Particularly, to take into account the errors propagation in computing RDI, the input variables (precipitation and temperature data) were simulated using a geostatistical simulation approach. A set of 500 alternative stochastic images of the variables were generated and the expected value and standard deviation for RDI values were mapped.

**Keywords:** Drought, RDI, Calabria, geostatistics, stochastic simulation.

### 1. INTRODUCTION

Water resources concerns have become widespread in a global context due to the growing interconnection with other development-related issues and also with social, economic, environmental, legal, and political factors at every scale. In this scenario, the knowledge of drought phenomena plays an important role for an appropriate planning and management of water resources [1], such that drought has attracted the interest of many researchers in recent years. Different drought events have affected Europe during the last decades [2-5], with impacts on public water supply, on industrial and agricultural production, and on the environment and, as consequence of the global warning, Southern Europe will be affected by more prolonged and severe drought events [6]. Drought originates from a deficiency of precipitation over an extended period of time. Several studies have detected rainfall changes both on global [7-8] and regional scales [9-

10] associated with global warming during the last 20 years. The implications of these changes are particularly significant for areas already under stress, such as the Mediterranean Basin, that suffer from a water shortage due to a combination of a dry climate (or a highly seasonal rainfall regime) and excessive water demand [11]. Studies involving Italian long records confirm a decrease in precipitation trends over Italy, with a very significant rainfall reduction in the southern regions during the last 50 years [12-15], in particular in the Calabria region [16-21]. However, other climatic factors such as temperature, wind and relative humidity, can influence drought severity.

In the study of the drought phenomenon drought indices able to objectively quantify climate conditions are usually required. Several drought indices have been proposed to monitor the various kinds of drought in different areas [22-23], among them, the Palmer Drought Severity Index (PDSI) [24] and the Standardized Precipitation Index (SPI) [25] are the most widely used. The SPI is based on the assumption that drought variability is mainly controlled by variations in precipitation field alone. Thus, the lack of any information on temperature field, the basic variable for climate change studies, appears questionable. In fact tendencies towards increasing temperatures during the last decades have been observed in several regions around the world and it is expected that such long-term trends may affect the intensity and duration of drought events.

Recently, a new drought index has been proposed: the Reconnaissance Drought Index (RDI). The RDI [26-27] has been developed to estimate a water deficit and it is based on the ratio between precipitation and potential evapotranspiration (ET), and can be computed for different time scales. The index, in its standardized form, can be easily compared with the SPI. However, using potential ET instead of actual ET makes it the index to approach an aridity index. Tsakiris et al. (2007), applied the SPI and the RDI in two river basins in Greece concluding that although the RDI generally responds in a similar trend to the SPI, it is more sensitive and suitable in cases of a changing environment. Pashiardis and Michaelides (2008) found that SPI and RDI respond in a similar way and can be both used to analyze drought condition in Cyprus. Razieli et al. (2011) show that in Iran temperature is noticeably increased during the last decade and so they discussed the effectiveness of using the RDI in capturing the impact of increasing temperature and

evapotranspiration in semi-arid regions on drought characteristics.

Geostatistical methods were developed to create mathematical models of spatial correlation structures [31] with a variogram as the quantitative measure of spatial correlation. The interpolation technique, known as kriging, provides the best (in a least-squares sense), unbiased, linear estimate of a regionalized variable in an unsampled location. One development of geostatistics is the stochastic simulation [32], which represents an alternative modelling technique, particularly suited to applications where global statistics are more important than local accuracy. A simulation tries to reproduce the essential statistical characteristics of the data distribution, such as a histogram and spatial continuity, computing a set of alternative stochastic images of the random process (simulations) which define a conditional probability distribution and their post-processing allows uncertainty assessment to be performed [33].

The main objective of the study was to assess the drought severity in a southern Italy area (Calabria region) by using the RDI and to map its spatial distribution and uncertainty.

## 2. STUDY AREA AND DATASET

Calabria is a region occupying the southern part of the Italian peninsula (Fig. 1) with a surface of 15,080 km<sup>2</sup> and a coastline of 738 km on the Ionian and Tyrrhenian seas. In the North, it borders Basilicata region for 80 km. Calabria has an oblong shape with a length of 248 km and a width ranging between 31 and 111 km. Although Calabria does not have many high summits, it is one of the most mountainous regions in Italy (Fig. 1): 42% of the land is mountainous, 49% hilly and only 9% is flat. The maximum elevation is 2,267 m a.s.l., while the average elevation is 597 m a.s.l.

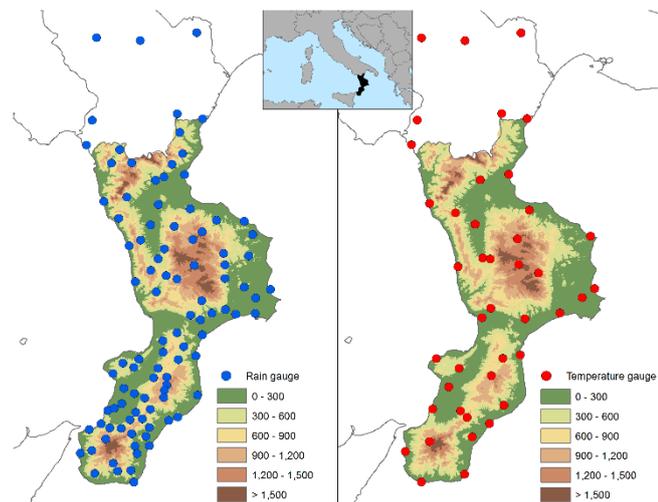


Fig.1. Study area and location of the weather station.

The data used in this study are a set of monthly precipitation and temperature series relative to the period 1921-2010 collected by the former Italian Hydrographic Service. When the number of years of observations was too low for statistical purposes or when there were too many gaps in the series (less than 30 available years of data) the station series were discarded from the dataset. As a result, 93 rainfall

series out of total of 318, with an average density of 1 station per 162 km<sup>2</sup> and 35 temperature series out of total of 141, with an average density of 1 station per 431 km<sup>2</sup> were selected. Moreover to improve the spatial analysis in the border area of the region, 7 rainfall and temperature series of the Basilicata region have been used.

## 3. METHODOLOGY

Dry and wet conditions at the selected stations have been assessed applying the RDI. The computation of RDI is based on the ratio of total precipitation (P) to potential evapotranspiration (PET) accumulated over the selected time scale (k). On the annual basis (k=12), we have:

$$a^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \quad (1)$$

with  $P_{ij}$  and  $PET_{ij}$  the precipitation and potential evapotranspiration of the j-th month of the i-th year. The standardized RDI is computed following a similar procedure to the (1) used for the standardized precipitation index (SPI) computation [27], and is given by:

$$RDI_{(k)}^{(i)} = \frac{y_{(k)}^{(i)} - \bar{y}_k}{\sigma_{yk}} \quad (2)$$

with  $y^{(i)} = \ln(a^{(i)})$ ,  $\bar{y}_k$  arithmetic mean and  $\sigma_{yk}$  standard deviation.

The Hargreaves equation [31] can be written as:

$$PET = 0.0023R_a(T + 17.8)\sqrt{(T_{max} - T_{min})} \quad (3)$$

where PET is the computed reference evapotranspiration (mm d<sup>-1</sup>);  $R_a$  is the water equivalent of the extraterrestrial radiation (mm d<sup>-1</sup>) computed according to Allen et al. (1998);  $T_{max}$ ,  $T_{min}$  and T are the daily maximum, minimum and mean air temperature (°C), with T calculated as the average of  $T_{max}$  and  $T_{min}$ . 0.0023 is the original empirical coefficient proposed by Hargreaves and Samani (1985).

Uncertainty analysis [35] (also called error propagation analysis) is an important tool to know how uncertainties in both model parameters and data propagate through the model [36]. Model uncertainty is generally difficult to quantify, but one method to do that is the generation of an adequate random input data set realizations and considers the joint distribution of all input variables. A suitable geostatistical approach is sequential Gaussian simulation, which draws alternative, equally probable, joint realizations of a regionalised variable [37, 38]. Differences between the realizations provide a measure of spatial uncertainty and allow us to carry out an error analysis. Among the simulation techniques, in this work the turning bands method with external drift [38] has been

used. An external drift was used because the weather stations having temperature data with more than 30 years of observations were sparse and few (only 42). Moreover, temperature cannot be assumed stationary at regional scale and elevation, which is an additional and denser information easily available, can improve the temperature estimation.

The proposed approach consisted in the following steps:

1. generating 500 set of input attributes realizations at nodes of a 250-m square grid using the turning bands method. Elevation as external drift to simulate temperature data;
2. computing for this set of inputs realizations, the potential evapotranspiration using Eq. (3) and RDI through Eqs. (1) and (2);
3. for each input and output attributes, computing average and standard deviation of the simulated values at each cell to produce the maps of the expected values at any given location and the ones of their standard deviation.

The uncertainty in model predictions has been quantitatively evaluated from the replicate stochastic images.

#### 4. RESULTS AND DISCUSSION

Figure 2 shows the maps of mean annual precipitation (left) and reference evapotranspiration (right) obtained by post-processing the 500 simulations. As input for ET model were used the 500 realizations of temperature data.

The maps of expected value and standard deviation of simulations for  $\alpha$  are reported in Fig. 3. A visual inspection of the maps (Fig. 3) shows clearly that there are extended areas characterised by high uncertainties localised on the mountains areas and in the north-western portion of the region. The higher values of  $\alpha$  are estimated in correspondence to the mountainous areas (Fig. 3), which have generally the higher uncertainties (higher values of standard deviation).

The Standardised RDI (Eq. (2)) behaves in a similar way to the standardized precipitation index (SPI) and therefore the interpretation of the results is similar because the same thresholds as SPI can be used (Fig. 4).

There are mainly three areas showing the most severe drought (orange-red areas in Fig. 4).

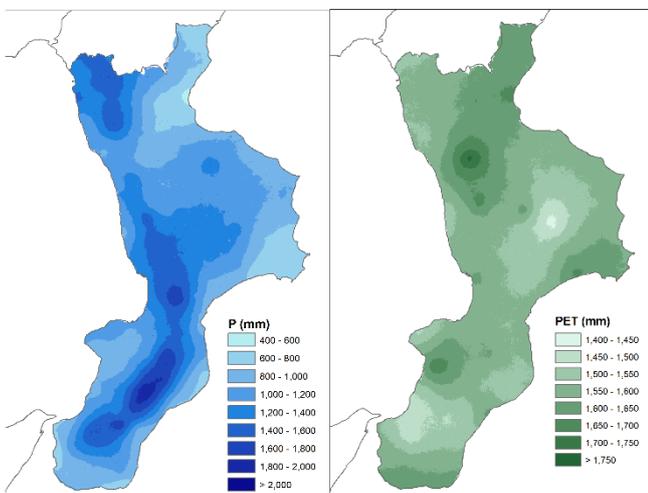


Fig. 2. Maps of mean annual precipitation (left) and reference evapotranspiration (right) of the study area.

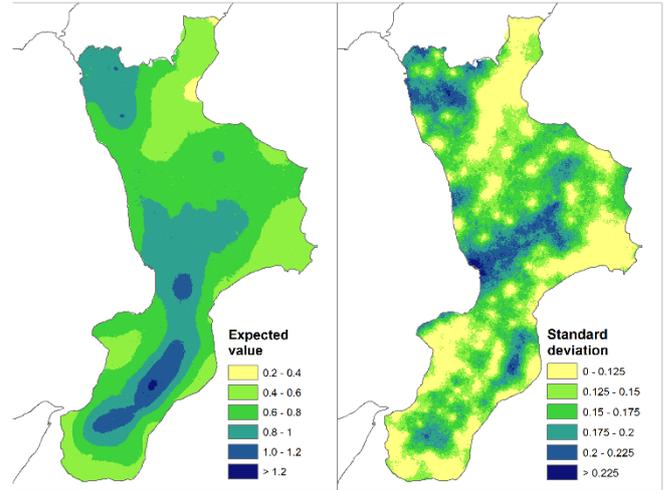


Fig. 3. Maps of expected value (left) and standard deviation (right) of simulations for  $\alpha$ .

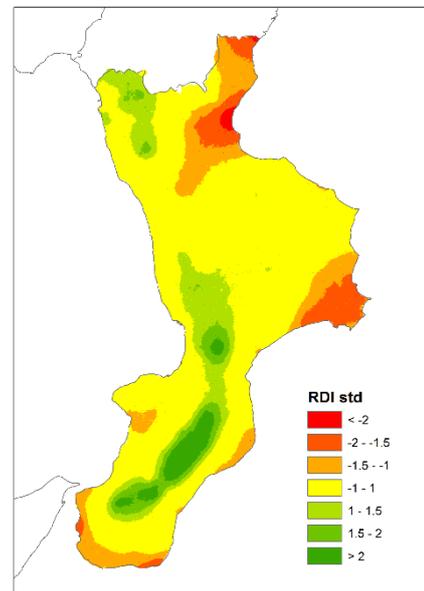


Fig. 4. Map of standard deviation for standardized RDI

#### 5. CONCLUSIONS

The study allowed to assess the drought severity in a southern Italy area (Calabria region) by using the RDI and to map its spatial distribution and uncertainty.

This approach has showed that it is possible to produce maps of uncertainty, which can be more useful than the simple extrapolations of estimation points.

The quality of spatial prediction depends on the uncertainties of the data used in the analysis; therefore map makers should convey the accuracy of the maps they produce.

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