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WATER RESOURCES EVALUATION UNDER CLIMATIC TREND EFFECTS IN MEDITERRANEAN CATCHMENTS

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Introduction

The availability of water in the Mediterranean areas in sufficient quantities and adequate quality represents a significant problem of European dimension. The potential impacts of climate change on hydrological response are of significant importance in these regions, where climate exhibits strong seasonality and the availability of water in the dry season determines the feasibility of multiple crop rotations. Based on a coupling of a stochastic rainfall model and the IHACRES rainfall-runoff model, this paper presents a simple Monte Carlo procedure to predict the potential impact of climate change scenarios on the hydrological flow regime (and hence water resources availability) in the Belice river catchment, south west Sicily.

The stochastic rainfall model daily precipitation is a well known two-state model merging a non homogenous First-Order Markov Chain to describe rainfall occurrences and a Weibull distribution to describe daily rainfall amount. This weather generator, calibrated using the actual rainfall and mean temperature data available at basin scale, has been used to translate future expected daily rainfall and mean temperature changes from simulations of the Hadley Centre Ocean-Atmosphere General Circulation Model (HadCM3) into useful information at local scale.

The IHACRES conceptual model with a configuration of one parallel linear channel and linear reservoir, corresponding to 'quick' and 'slow' components of runoff is hence fed by the synthetic daily series coming from the stochastic rainfall model (i.e. rainfall and temperature) in order to generate long synthetic daily discharge series corresponding to three future time-slices. Finally, these series were elaborated to quantify the impact of climate change on water resources availability, drought frequency, etc.

Case study area

For the application of the models data from:
- 13 pluviometric stations;
- 1 hydrometric station (Belice at Belice);
- 4 thermometric stations

have been used.

Available data:
Unbroken daily time series of average discharge at each streamgauges, rainfall and temperatures (min and max).
The calibration period is 5 years long ranging from 1970-1975 for all series.

Stochastic rainfall generator

The model applied is a well known chain-dependent-process stochastic model for daily precipitation (Wilks, 1998) structured in a two-state architecture: a first-order non-stationary Markov chain for modeling the rainfall occurrences, and a probabilistic model for modeling the rainfall occurences. The model is capable to incorporate trend effects in rainfall and temperature and consequently to generate series with statistical properties influenced by the climatic change . The first-order Markov chain model for X_t follows from the assumption that probability of wet/dry day is fully defined if precipitation occurred or did not only on the previous day (t-1).

$$Pr\{X_t = 1 | X_{t-1} = 0\} = p_{01}$$
$$Pr\{X_t = 1 | X_{t-1} = 1\} = p_{11}$$

Equivalently, the complementary conditional probabilities are:

$$Pr\{X_t = 0 | X_{t-1} = 0\} = p_{00}$$
$$Pr\{X_t = 0 | X_{t-1} = 1\} = p_{10}$$

With:

$$p_{00} = 1 - p_{01}$$
$$p_{10} = 1 - p_{11}$$

Nonzero precipitation amounts ht are simulated here using the Weibull distribution (Maidment, 1993) with the probability density function:

$$F(x) = (k/\lambda)(x/\lambda)^{(k-1)} e^{-(x/\lambda)^k} \quad \text{for } x > 0$$

The model was calibrated against 5 years-long daily rainfall series available from the 13 rainfall stations used for the study. The agreement between the simulated and observed monthly rainfall depths, number of dry and wet days is shown in figs. 5,6 and 7.

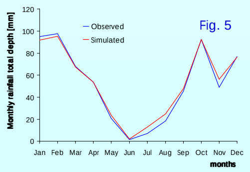

Fig. 5

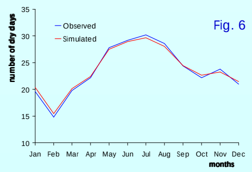

Fig. 6

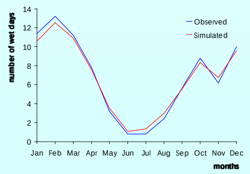

Fig. 7

Figs. 8 and 9 show the generated scenarios compared with the actual scenario under the hypothesis that only the precipitation amount distribution parameters are affected by the climate change while the table reports actual and future scenario distribution parameters.

MEAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NOW	**8.3**	**7.4**	**6.0**	**6.8**	**6.5**	**1.8**	**8.6**	**7.1**	**7.7**	**10.5**	**7.7**	**7.6**
2025 SCENARIO	8.9	6.9	5.9	6.2	6.0	1.7	7.5	6.1	6.4	12.2	8.0	9.5
2050 SCENARIO	8.8	7.3	5.7	6.8	5.3	2.0	6.8	5.6	6.5	11.2	7.3	7.8
2080 SCENARIO	8.9	6.8	5.8	6.6	5.1	1.7	6.6	4.7	5.5	10.3	6.8	8.4
DEV ST	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
NOW	**10.1**	**7.5**	**5.8**	**7.2**	**7.7**	**2.2**	**13.1**	**12.1**	**12.3**	**13.4**	**10.5**	**9.4**
2025 SCENARIO	10.9	7.7	5.3	6.4	7.4	2.0	16.5	9.2	12.0	15.3	11.5	11.8
2050 SCENARIO	11.3	7.8	4.9	7.5	6.5	3.1	6.3	6.8	11.3	15.0	11.0	9.5
2080 SCENARIO	10.9	7.5	5.6	8.2	6.6	2.2	6.7	5.1	10.0	13.4	11.2	11.7

Tab.1

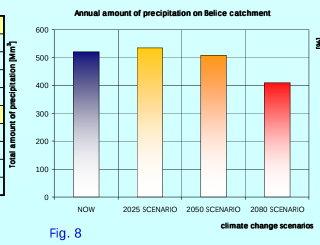

Fig. 8

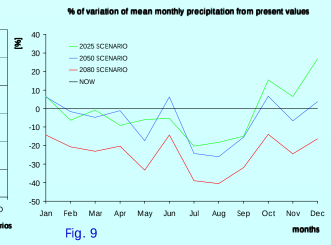

Fig. 9

Conclusions

- A robust model framework for the evaluation of changes in water resources availability under climate change scenarios as been set up;
- Synthetic rainfall, temperature and runoff series generated by the models under current scenario showed a robust capability of the models to perform synthetic generation. The same series were obtained under climate change future scenarios. To achieve the latter, synthetic future scenarios has been derived by the Meteorological Group of University of Balearic Islands which supplied the trend parameters (i.e. mean and variance) of monthly rainfall and temperature series from now to 2085;
- Future climate change scenarios show a negative trend in annual amount of precipitation and a positive trend in annual mean temperature leading to a negative trend of total water resources;
- These results pointed out the necessity to perform climate scenario analysis for any planning or management purpose in the field of water resources engineering.

HadCM3 Ocean-Atmosphere General Circulation Model

The atmosphere-ocean coupled global models (AOGCMs) are well-established tools to study future climate change. Their application to the regional climatic processes is limited due to their coarse spatial resolution. To improve our understanding from global climate model projections related to regional analysis of mean climatic changes there are several approaches as model output statistics or statistical downscaling in which are included the weather generators. HadCM3 model is the last Hadley centre's coupled ocean-atmosphere GCM with a horizontal resolution of 2.5 x 3.75 degrees and 19 vertical levels, equivalent to a spatial resolution of 278 km x 295 km in the latitudes of interest (~ 45º) (Further information: http:// www.metoffice.com/research/hadleycentre/).

Expected changes in the future precipitation and mean temperature regimes have been obtained from simulations of the HadCM3. Estimated greenhouse effect concentration gases for the A2 and B2 scenarios, developed by the IPCC in 1996, were used as the global radiative forcing for the performance of the runs extending from mid 19th century until the end of 21st century. Percentage changes in monthly rainfall and mean temperature and their standard deviation between a 30-years period from the present (1971-2000) and three 11-years future time-slices (2020-30, 2045-55 and 2075-85) have been calculated (Figs. 1,2,3 and 4). Then, monthly precipitation and temperature changes in mean value and variability are applied to the observed daily rainfall series at Belice river catchment to obtain the future rainfall and temperature scenarios.

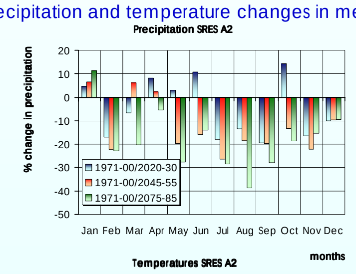

Fig.1

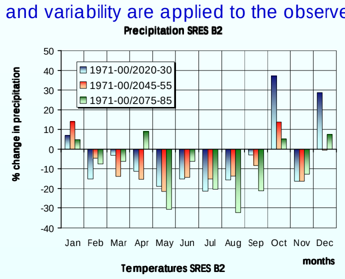

Fig. 2

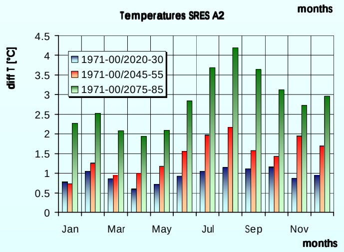

Fig. 3

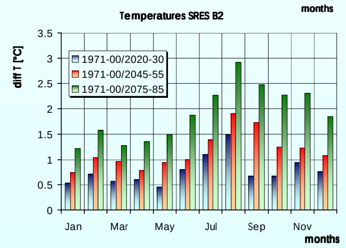

Fig. 4

Stochastic temperatures generator

For the generation of synthetic temperature generation a classical Auto Regressive Moving Average model (ARMA) has been applied (Maidment, 1993).
In particular, an ARMA (1,1) model expressed by the following relation was used: $y_t = \phi y_{t-1} + \varepsilon_t - \theta \varepsilon_{t-1}$
The model was calibrated against a 5 years-long daily mean temperature series obtained as the average of the daily mean temperature recorded at 5 thermometric stations within the Belice catchment. Parameters of the model were obtained by maximum likelihood estimation.
Figures 10, 11 and 12 show the generated scenarios compared with the actual scenario in terms of mean monthly, annual temperature and % of variation.

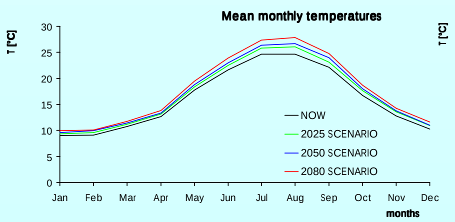

Fig. 10

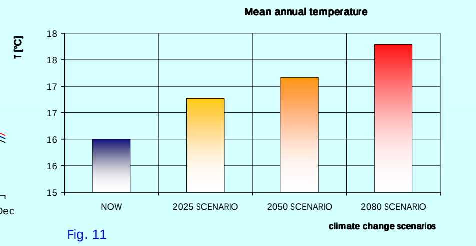

Fig. 11

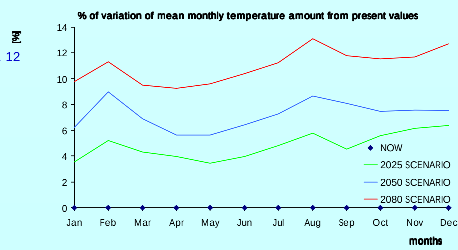

Fig. 12

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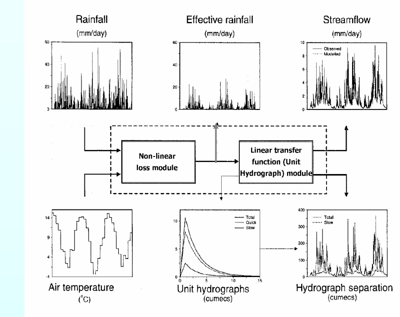
The rainfall-runoff model – the IHACRES

In the IHACRES (Identification of Hydrographs And Components from Rainfall, Evapotranspiration and Streamflow data, Jakeman et al., 1990) the rainfall-runoff processes are represented by two modules: (1) a non linear loss module transforms precipitation to effective rainfall from by considering the influence of the temperature, and (2), after this, a linear module based on the classical convolution between effective rainfall and the unit hydrograph to derive the total streamflow.



Non-linear loss module

$$u_k = s_k \cdot r_k$$

$$s_k = \frac{r_k}{c} + \left(1 - \frac{1}{\tau_w(T_k)}\right) \cdot s_{k-1} \qquad s_0 = 0$$

$$\tau_w(T_k) = \tau_0 e^{0.062 \cdot f \cdot (20 - T_k)} \qquad \tau_w(T_k) > 1$$

where:
uk effective rainfall;
rk total rainfall;
sk storage index (0<sk<1);
T_k air temperature (°C)
τ_0 τ_w value for T=20 °C;
f temperature modulation factor
c parameter chosen to constrain the volume of effective rainfall to equal runoff ;
k time

The Ye et al. (1997) modification of the model to for semi-arid regions has been applied:

$$u_k = (s_k - l)^p \cdot r_k \quad \text{se} \quad s_k > l$$
$$u_k = 0 \quad \text{in other cases}$$

where:
l threshold parameter
p the exponent of a power-law used to describe the non-linearity

The model was calibrated against a 5 years-long daily rainfall series available from the 13 rainfall stations used for the study The model was calibrated using as input the longest unbroken daily time series of discharge at each streamgauges (a 5 years-long daily series) , the rainfall and the air temperature spatially averaged on the Belice at Belice subcatchment Belice (807.2 km2). The calibration period is 5 years long ranging from 1970-1975 for all series. Table 2 and figure 13 show, respectively, model parameters and the flow duration curve obtained from the calibration of the model for the subcatchment used for the study.

Tab. 2

Parameters	
c	519.099
τ_0	3.252
f	6.794
x_0	0.071
x_1	0.603
k_1	3.805
k_2	69.398
l	2.200
p	1.822

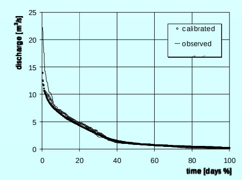


Fig. 13

Figs. 14 and 15 show the generated scenarios compared with the actual scenario in terms of annual amount of water resources and % of variation

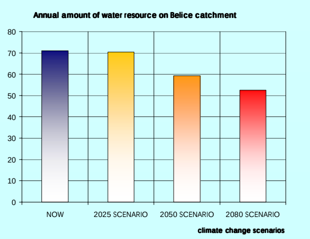


Fig. 14

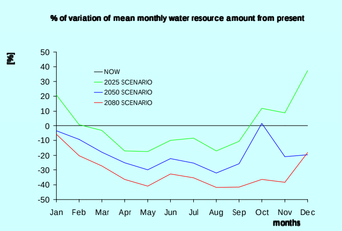


Fig. 15

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