

FUTURE PATTERN OF DROUGHT OVER GREECE UNDER GLOBAL WARMING

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ABSTRACT

This study investigates the effect of global warming on drought patterns over Greece by comparing the projected climate periods 2021-2050 and 2071-2100 from the regional climate model RACMO2 with the 1961-1990 observed base period. The projected daily mean temperature and precipitation data at a high horizontal resolution (25 km) from runs produced within the framework of the EU –funded ENSEMBLES project, are translated into drought climatology. The new multi-scalar Standardized Precipitation–Evapotranspiration index SPEI based on monthly precipitation and evapotranspiration data, the widely used multi-scalar Standardized Precipitation Index SPI, based on monthly rainfall data and the Effective Drought Index EDI, based on daily precipitation data are tested in identifying drought variability in Greece.

1 INTRODUCTION

The Mediterranean region is vulnerable to climate change particularly due to its sensitivity to drought and rising temperatures (IPCC 2007a; Giorgi 2006; Gao and Giorgi 2008). Regional climate model (RCM) simulations can provide useful insight into the climate of a region provided they can adequately reproduce the observed climate. Few studies on climate change impacts on droughts have employed easily handled meteorological or agricultural drought indices. Projections of the drought climatology over Greece have been based on the standardized precipitation index SPI (McKee et al. 1993, 1995) by Loukas et al (2007, 2008), Vasiliades et al. (2009), and Tzabiras et al. (2010, 2011), or the Palmer drought severity index PDSI (Palmer, 1965) and the self-calibrated Palmer drought severity index sc-PDSI (Wells et al., 2004) by Mavromatis (2007, 2010).

In this study, the projected daily precipitation from the regional climate model

RACMO2 is employed in the easily handled effective precipitation index EDI (Byun and Wilhite, 1996) which quantifies the drought intensity in daily time steps for identifying the future pattern of drought over Greece. The index has already been used for investigating the effects of global warming on droughts over Asia (Kim and Byun, 2009). Furthermore, future drought scenarios are estimated for Greece using monthly projections of precipitation or temperature and precipitation in SPI or the new standardized precipitation-evapotranspiration index SPEI, respectively. The new standardized index is multi-scalar as SPI, but sensitive to evapotranspiration and has been selected as particularly suited to detecting, monitoring and exploring the consequences of global warming on drought conditions (Vicente-Serrano et al, 2010).

2 MATERIALS AND METHODS

2.1 Data

Daily output data, from the RACMO2 regional climate model, developed at KNMI in the Netherlands, developed within the framework of the ENSEMBLES project are used. RACMO2 has a horizontal resolution of $25 \text{ km} \times 25 \text{ km}$, which reproduces a European-Mediterranean grid of 85° longitude by 95° latitude grid cells in a rotated latitude-longitude projection. The model uses initial and boundary conditions from the General Circulation Model (GCM) ECHAM5. The high spatial resolution of RACMO2 enables a satisfactory representation of the sea area and the islands. The control run represents the base period 1961-1990 and is used here as a reference for comparison with future projections for the periods 2021-2050 and 2071-2100. The future period simulations of the model, 2021-2050 and 2071-2100 are based on the IPCC SRES A1B scenario. The A1B scenario provides a good mid-line scenario for carbon dioxide emissions and economic growth (Alcamo et al., 2007).

The observational data, obtained from the National Meteorological Service of Greece, consists of daily and monthly weather records of precipitation and monthly records of mean temperature for the period 1961-1990 for 24 stations evenly distributed on the Greek area. Table 1 presents the characteristics (latitude/longitude) for each station of this study.

2.2 Methods

1.1.1 Model performance in temperature and precipitation present-day climate

To test the validity of RACMO2 output, linear regressions and “difference measures” are carried out between average monthly values of observed and projected precipitation/temperature for the period 1961-1990 for the set of the 24 stations of the study. The same analysis is performed between average julian day values of observed and projected precipitation for the period 1961-1990 for the 24 stations of the study. For a further comparison, the coefficient of variation (CV) is estimated over all 24 stations of the study for the 12 mean monthly values of the observed precipitation/temperature, as well as for the 365 average julian day values of the observed precipitation. CV is expressed for each mean monthly or average julian value as the percentage of the standard deviation of the corresponding monthly/julian values towards their mean monthly/julian value.

Table 1. Mean frequency (MF) of drought events, as expressed by the indices SPEI₁₂, SPI₁₂ and EDI₃₆₅, for every station of the study during the present (1961-1990) or the future (2071-2100) period

Station	Lat.	Long.	SPEI ₁₂ -present MF (per year)	SPEI ₁₂ -future MF (per year)	SPI ₁₂ -present MF (per year)	SPI ₁₂ -future MF (per year)	EDI ₃₆₅ -present MF (per year)	EDI ₃₆₅ -future MF (per year)
Florina	40°48	21°25	0.172	0.172	0.167	0.167	0.103	0.138
Mikra	40°31	22°58	0.379	0.448	0.333	0.333	0.207	0.241
Alex/lis	40°51	25°26	0.344	0.344	0.233	0.200	0.310	0.241
Kozani	40°17	21°47	0.241	0.241	0.233	0.233	0.379	0.379
Kerkira	39°37	19°55	0.207	0.310	0.200	0.233	0.379	0.448
Ioannina	39°40	20°51	0.241	0.344	0.200	0.233	0.310	0.241
Larisa	39°39	22°26	0.344	0.344	0.200	0.233	0.414	0.344
Agxialos	39°13	22°48	0.379	0.379	0.400	0.400	0.379	0.379
Mitilini	39°04	26°36	0.414	0.414	0.367	0.433	0.344	0.448
Agrinio	38°37	21°33	0.241	0.276	0.233	0.233	0.241	0.310
Andravida	37°55	21°17	0.276	0.310	0.233	0.200	0.276	0.414
Skiros	24.29	38.58	0.070	0.103	0.067	0.067	0.241	0.276
Tripoli	37°32	22°24	0.241	0.276	0.167	0.233	0.276	0.276
Elliniko	37°54	23°45	0.344	0.379	0.333	0.367	0.344	0.344
Kalamata	37°04	22°01	0.207	0.310	0.200	0.200	0.310	0.310
Naxos	37°06	25°23	0.379	0.414	0.300	0.367	0.448	0.379
Methoni	36°50	21°42	0.344	0.379	0.300	0.300	0.379	0.379
Milos	36°44	24°26	0.482	0.379	0.333	0.400	0.414	0.310
Kithira	36°08	23°01	0.344	0.379	0.200	0.267	0.344	0.344
Rhodes	37°24	28°05	0.344	0.344	0.300	0.267	0.310	0.379
Iraklio	35°20	25°11	0.379	0.310	0.233	0.233	0.344	0.344
Ierapetra	35°00	25°44	0.517	0.448	0.367	0.400	0.207	0.241
Siteia	35°12	26°08	0.344	0.414	0.333	0.333	0.310	0.172
Timbaki	35°00	24°46	0.379	0.620	0.300	0.300	0.344	0.448

1.1.2 Future drought scenarios

The outputs of the RCM simulation are downscaled and bias-corrected by using a change factor (CF) method. The method involves adjusting of the observed monthly temperature by adding the difference in mean monthly temperature predicted by the climate model between the periods (2071-2100) or (2021-2050) and (1961-1990), to obtain perturbed monthly temperature for the period (2071-2100) or (2021-2050) respectively. The perturbed monthly precipitation for the future periods (2071-2100) or (2021-2050) is obtained by multiplying the precipitation ratio of mean monthly precipitation predicted by the climate model for the periods (2071-2100) or (2021-2050) to mean monthly precipitation predicted by the climate model for the period (1961-1990) respectively, with the corresponding observed monthly precipitation. Similar steps of this process are followed for the calculation of the daily values of the perturbed precipitation series for the periods (2071-2100) and (2021-2050).

The perturbed precipitation and temperature climatology is then translated into the change in drought climatology using the standardized precipitation index SPI, the standardized precipitation evapotranspiration index SPEI and the effective drought index EDI. For this purpose, the observed and the two perturbed monthly precipitation time series are used in the estimation of the SPI_{12} index, while the observed and the two perturbed monthly time series for precipitation and temperature are used for the estimation of the $SPEI_{12}$ index. On the other hand, the observed and the two perturbed daily precipitation time series are used in the calculation of the EDI_{365} .

For calculating the standardized precipitation index (according to McKee et al.1993;1995), the long term time series of monthly precipitation values (observed 1961–1990, perturbed 2021-2050, perturbed 2071-2100) fit a probability density function. The cumulative probability of an observed precipitation amount is computed and the inverse normal (Gaussian) function is then applied to the cumulative probability. As a result the dimensionless SPI is estimated as the discrete precipitation anomaly of the transformed data, divided by the standard deviation of the transformed data. As SPI can track drought on multiple timescales, in this study the index SPI_{12} is calculated for each month, at a 12-month timescale, reflecting long-length drought events.

The calculation of SPEI (Vicente-Serrano et al, 2010) is based on the original SPI calculation procedure, but with modifications to include potential evapotranspiration (PET). The simplest approach to calculate PET (Thornthwaite, 1948) based on mean monthly temperature is used. The SPEI uses the monthly difference between precipitation (P) and PET. The log-logistic distribution is chosen to model (P-PET) values and the resulting cumulative probabilities are transformed into a standardized variable. Therefore, the log-logistic distribution is used to calculate the SPEI, whereas the Pearson III distribution is usually used to calculate SPI.

Using only daily precipitation data (observed 1961-1990, perturbed 2021-2050, perturbed 2071-2100), the effective precipitation index EDI is calculated with a daily time step (Byun and Wilhite, 1996) for each station of the study. The first step is the calculation of EP, a function of the current day's precipitation and weighted precipitation over a defined preceding period:

$$EP = \sum_{m=1}^N \left[\left(\sum_{i=1}^m P_m \right) / m \right] \quad (3)$$

where N is the duration of the preceding period and P_m the precipitation of m-1 days previously. The time series of EP values is converted to deviations from the mean (DEP) and the standard deviations STDEV(DEP) of these DEP values are then estimated for each day. The EDI index is then calculated as:

$$EDI = DEP / STDEV(DEP) \quad (4)$$

This index expresses the amount of precipitation required for the recovery from the accumulated water shortage since the beginning of a drought event. In particular, the EDI_{365} index is defined for a time period of accumulation of 365 days.

Finally, the effect of climate change on droughts is assessed from the changes in the mean frequency of drought events, which are characterized by values of the drought index smaller than -1.0 (Kim and Byun, 2009).

3 RESULTS

3.1 Model performance in temperature and precipitation present-day climate

The results from the linear regressions and the “difference measures” between average monthly observed and projected precipitation/temperature for the period 1961-1990 for the 24 stations of the study show that observed and projected precipitation are rather well correlated [correlation coefficient (R) = 0.846, index of agreement (IA) = 0.891]. The root mean squared error (RMSE) though is equal to 49 % and the mean bias error (MBE) is equal to -24 %. The results for the observed and projected monthly temperatures are much better (R = 0.983, IA = 0.980, RMSE = 11 %, MBE = -8 %). The regression analysis and the “difference measures” between the average julian day values of observed and projected precipitation for the period 1961-1990 for the 24 stations of the study show slightly worse results as compared to the monthly precipitation projections (R = 0.781, IA = 0.845, RMSE = 51 %, MBE = -24 %).

Jones et al. (2003) have defined acceptable differences of around $\pm 1^\circ\text{C}$ for monthly temperature due to elevational differences in the way monthly temperature is calculated by the models and observations and for the other variables of being within about 30% of the coefficient of variation (CV) of the measured variable. The corresponding estimation of the CV over all 24 stations of the study for the 12 mean monthly values of the observed precipitation/temperature, shows that with the exception of months May and June for temperature and of months October, November and December for precipitation, the estimates of the CV of the modelled data are within about 30% of the corresponding values of the observations. The estimated coefficient of variation over all 24 stations of the study for the 365 average julian day values of the observed precipitation shows that all the CV estimates of the modelled data were within about 30% of the corresponding values of the observations. Since the deviations between observed and modelled data are within the accepted ranges, the RACMO2 data are considered as close enough to reality and hence the projected temperature and precipitation data for the considered future time periods may rather provide useful information.

3.2 Future drought scenarios

The monthly SPI_{12} and $SPEI_{12}$ or the daily EDI_{365} obtained from the observed data as compared with the ones estimated directly from the RACMO2 outputs (for the period 1961-1990) are quite different. Therefore, all three indices are computed from the perturbed time series in order to indicate the drought responses to the future climate changes. The temporal evolution of the three drought indices under the present (1961-1990) or future (2021-2050, 2071-2100) scenarios is apparent in Figure 1 for 2 selected stations (Ierapetra and Elliniko). It is evident that drought seems to be somehow more intense during some periods in the future years. When examining the temporal evolution of the present (1961-1990) and future (2021-2050, 2071-2100) values of the three estimated indices all over the stations of the Greek area, it is obvious that all three indices capture more intense future drought events over the southern and drier part of Greece. Table 1 presents the mean frequency of drought events per year as indicated by SPI_{12} , $SPEI_{12}$ and EDI_{365} for every station during the present or the future (2071-2100) period. According to SPI_{12} , the mean frequency per year is expected to slightly increase in 10 stations, whereas according to $SPEI_{12}$ 14 stations of the study are about to experience drier conditions. $SPEI_{12}$ captures dry conditions more frequently even during the present period. Especially Timbaki (in southern Greece), is about to suffer enough drier conditions than the present day according to $SPEI_{12}$. It must be referred that according to SPI_{12} the mean frequency of drought events remains the same. Results based on EDI_{365} also show increase in the mean frequency of droughts for 10 stations of the study.

4 DISCUSSION AND CONCLUSIONS

The use of drought indices that include temperature data in their formulation is preferable, especially for applications involving future climate scenarios. The new drought index (SPEI) based on precipitation and potential evapotranspiration combines the sensitivity of PDSI to changes in evaporation demand (caused by temperature fluctuations and trends) with the simplicity of calculation and the multi temporal nature of the SPI (Vicente-Serrano et al, 2010). The SPI cannot identify the role of a temperature increase in future drought conditions. It cannot either account for the influence of temperature variability, whereas the SPEI can account for the possible effects of temperature variability and temperature extremes beyond the context of global warming.

All available GCM underestimate annual precipitation by about 20% for the Mediterranean basin (IPCC, 2007). Various RCMs for central Eastern Greece have been referred also as underestimating annual precipitation by about $33\pm 19\%$ (Zanis et al. 2008). Although RACMO2/KNMI has been tested as the best performing RCM model (Founda and Giannakopoulos, 2009), precipitation seems harder to be reproduced. On a mean monthly basis an adequate representation by the model is revealed, whereas correlation among daily precipitation data sets (observed and projected both for the period 1961-1990) revealed worse results. Considering though the results from the CV statistics, RACMO2 reproduces mean monthly temperature very well and mean monthly precipitation and average julian day precipitation reasonably.

The results mainly based on SPEI show that climate change may have an impact on the mean frequency or the intensity of droughts in Greece. This is in accordance with an

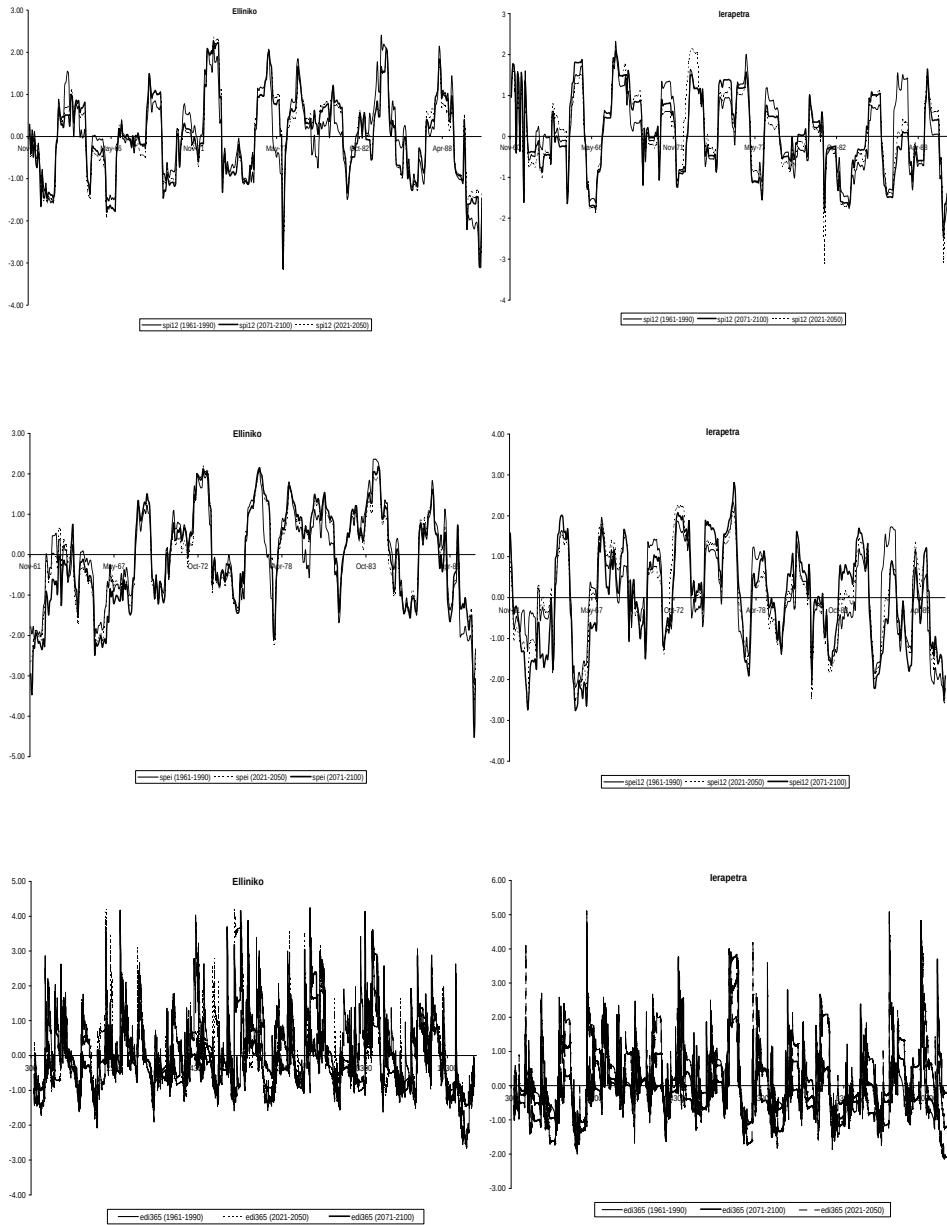


Figure 1. Temporal evolution of the SPI₁₂, SPEI₁₂ and EDI₃₆₅ indices under the present (1961-1990) and future (2021-2050, 2071-2100) scenarios for the stations Elliniko and Ierapetra

increase in future drought severity referred by a number of studies (Vicente-Serrano et al. 2010, Beniston et al. 2007, Sheffield and Wood 2008). The scientific community though should take into consideration whether the parameters of meteorological drought indices should be limitedly handled for the present climate. Projected changes associated with temperature have a higher degree of confidence than those associated with precipitation (Giannakopoulos et al, 2011). Thus, indices associated only with precipitation may be subject to higher levels of uncertainty and should be viewed with more caution.

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