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FUTURE DROUGHT PROJECTION FOR THE GREEK REGION

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Abstract

Drought is one of the most important factors of change. The epi-drops drought in one area are complex because they simultaneously affect many areas, such as climate, agriculture, the economy and in general the structure of society. This study deals only with the meteorological drought, particularly considering the phenomenon of drought through the index Standardized Precipitation Index (SPI). The Greece is characterized by frequent drought episodes that often exceed 10 consecutive days of drought (dry spells). Also, in recent years the area probably climate models have been used in a wide study of the impact of climate change in different regions on the planet. Rainfall data from five regional climate models (RCMs) have been used to calculate the SPI index in the Greek area, the reporting period and two subsequent periods by the end of the 21st century. All models show a decreasing trend of the SPI median during the period studied. For the first future period 2021-2050, there is a clear signal for a dry decade towards the end of the period that is most apparent in southern and island regions. On the other hand, in the second future period 2071-2100, there is an increasing trend resulting to normal or wetter years.
Keywords: *SPI index, climate regional models, Greece.*

Περίληψη

Η ξηρασία αποτελεί ένα από τους σημαντικότερούς παράγοντες του κλίματος. Οι επιπτώσεις της ξηρασίας σε μία περιοχή είναι σύνθετες διότι επηρεάζουν ταυτόχρονα πολλούς τομείς, όπως είναι το κλίμα, η γεωργία, η οικονομία αλλά και γενικότερα τη δομή της κοινωνίας. Η παρούσα μελέτη ασχολείται μόνο με τη μετεωρολογική ξηρασία, και ειδικότερα μελετά το φαινόμενο της ξηρασίας μέσω του δείκτη Standardized Precipitation Index (SPI). Η Ελλάδα χαρακτηρίζεται από συχνά επεισόδια ξηρασίας τα οποία πολλές φορές ξεπερνούν τις 10 συνεχόμενες ημέρες ξηρασίας (dry spells). Επίσης, τα τελευταία χρόνια τα κλιματικά περιοχικά μοντέλα έχουν χρησιμοποιηθεί ευρέος στη μελέτη των επιπτώσεων των κλιματικών αλλαγών σε διάφορες περιοχές στο πλανήτη. Τα δεδομένα βροχόπτωσης από πέντε περιοχίκα κλιματικά μοντέλα (RCMs) έχουν χρησιμοποιηθεί για τον υπολογισμό του δείκτη SPI στην ελληνική περιοχή, για τη περίοδο αναφοράς και δύο μελλοντικές περιόδους έως το τέλος του 21ου αιώνα. Όλα τα μοντέλα δείχνουν μία τάση ελάττωσης της διαμέσου του SPI δείκτη στη διάρκεια της μελετώμενης περιόδου. Για τη πρώτη μελλοντική περίοδο, 2021 με 2050, υπάρχει ένα σαφές σήμα για μία ξηρή δεκαετία προς το τέλος της περιόδου που είναι πιο εμφανής νησιωτικές περιοχές. Αντίθετα, στη δεύτερη μελλοντική περίοδο, 2071 με 2100,υπάρχει αυξητική τάση του δείκτη που σημαίνει περισσότερα κανονικά ή υγρά έτη.
Λέξεις κλειδιά: *Δείκτης ξηρασίας SPI, περιοχικά κλιματικά μοντέλα, Ελλάδα.*

1. Introduction

One of the most hazardous phenomenon in climatology is drought, it can be observed at any place, with any duration and in any time. It is also be consider as a complex phenomenon related to many different meteorological parameters (rainfall, snowpack, streamflow or other water supply indicators). It is difficult to identify the first and the last day of a drought episode, because there is a lag between its appearance and the observation of no rain. Moreover, the drought catastrophic impacts often continued after the occurrence of rainfall in a region. For those reasons, it is difficult to find a uniform scientific definition for drought: generally different regions present different drought definitions depending on the climatology and topography of the study areas. Drought is defined differently from region to region and according to the purpose of each researcher (WMO-World Meteorological Organization, 1975; Meteorological Office, 1991; Wilhite and Glantz, 1985). For that reasons, a drought episode can be considered unique with its own climatic characteristics and impacts.

Several drought indices were established to measure how much precipitation for a given time period has deviated from historically mean values .Many studies are dealt with the calculation of these indices and their comparison. One of the most widely used drought index is the Palmer Drought Sever Index (PDSI) index for which there are some limitations on its application (Alley, 1984). Briffa *et al.* (1994) used the PDSI index analyzing dry and wet summers in Europe. Jones *et al.* (1996) related atmospheric circulation with PSDI index and Szinell *et al*. (1998) studied the drought in Hungary using PDSI index. Dalezios *et al* (1991) applied the PDSI index in the central and northern region of Greece, while Maheras (2000) studied the drought in the Mediterranean region by calculating the normalized monthly precipitation anomaly (Standardized Precipitation Anomalies, SPA). McKee *et al*. (1993) developed the Standardized Precipitation Index –SPI, a drought index that identifies emerging droughts months sooner than the Palmer Index and it can be computed on various time scales. SPI is applicable in many regions in world. Pita (2000) applied the SPI index in Andalusia, Lana *et al.* (2001) in Catalonia, Seiler *et al*. (2002) in Argentina and Zhai *et al.*, (2010) in China. Anagnostopoulou (2003) studied drought in Greece using SPI for different time scales and related these indices with synoptic circulation patterns.

The purpose of this study is to compare projections of drought in Greece for the late 21st century between five different RCMs using SPI index. All the RCM simulations being analyzed here are based on the same emission scenario (SRES A1B), are nested into the same GCM (ECHAM5) and are operated at the same grid spacing. The outline of this paper is as follows. Section 2 describes the data and the methods used in the analysis of the drought results, which are introduced in section 3. Results of the model evaluation in the Greek region are discussed in section 3.1and 3.2. The scenarios of drought are presented and interpreted in sections 3.3 to 3.5. Finally, section 4 summarizes the results and draws conclusions.

2. Material and Methods

2.1. Material

RCM data by the ENSEMBLE project provides a series of high-resolution regional climate change scenarios for precipitation in Europe. Five RCMs driving by the same GCM (ECHAM5) was selected for this study: DMI (Danish Meteorological Institute), ICTP (Abdus Salam International Centre for Theoretical Physics), KNMI (Koninklijk Nederlands Meteorologisch Instituut), MPI (Max Planck Institute for Meteorology) and SMHI (Swedish Meteorological and Hydrological Institute). Model rainfall simulations are available for the control period (1961–1990) and two future sub-periods (2021-2050) and (2071–2100) using the SRES A1B emissions scenario. The closest grid points to the stations were selected for the analyses (Figure 1).

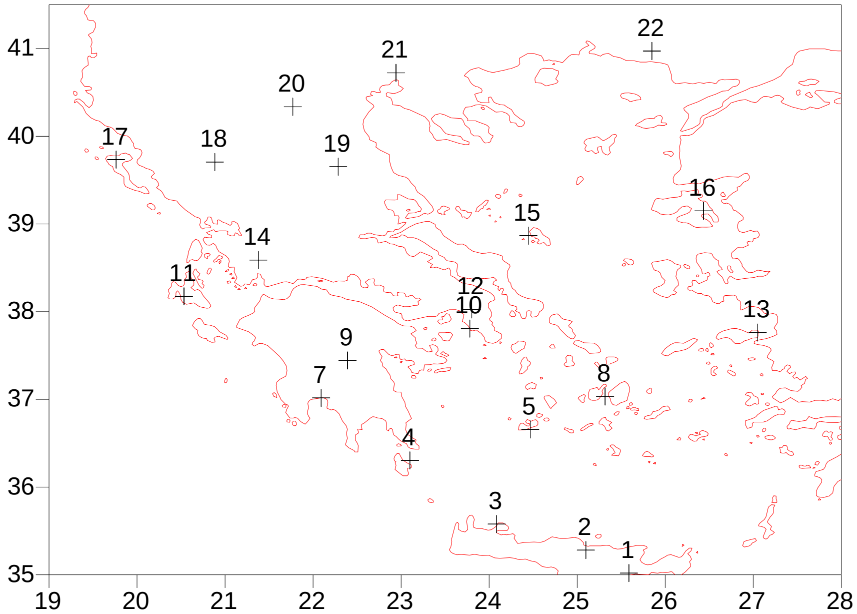

Figure 1 - The twenty two Greek grid points used in the study.

2.2. Methods

The Standardized Precipitation Index (McKee et al 1993) is based on the cumulative probability of a given rainfall event occurring at a station or a grid point. Because gamma distribution is appropriate to most cases of analyzing rainfall records (Lana *et al.*, 2001), the rainfall data of the station is fitted to it. This is done through a process of maximum likelihood estimation of the gamma distribution parameters, α and β allowing the rainfall distribution to be descripted by a mathematical cumulative probability function. Thus, the probability of rainfall being much smaller than the average rainfall will be low (0.2, 0.1, 0.01 etc), depending on the amount, while the probability of rainfall being equal to the average rainfall for that area will be about 0.5. Finally, the cumulative probability of gamma function transform into a standard normal random variable Z with mean of zero and standard deviation of one. This Z is the SPI index. SPI ranges from +3 to -3, with the -3 to be characterized as extremely dry conditions. More information on the mathematical background to the SPI can be found to Anagnostopoulou (2003).

SPI can be estimated for different time steps, three months, six months, 12 months, etc. For example, in order to estimate SPI6 for May 1985, six months rainfall totals (from December 1984 to May 1985) were used. In the present study only SPI12 was calculated using both datasets, once for station daily rainfall totals and secondly for the closer grid point to the stations of the five RCM models.

3. Results

3.1. Changes in Overall Dryness

Climate projections of the central values (mean/median) for the SPI show that Greek region tends towards drier overall conditions. The analysis will be focused on median values because the results for the mean and median SPI are extremely similar in severity and statistical significance. Figure 2 shows the agreement among selected RCMs combinations in the statistically significant direction of change for the median SPI12. Regions expected to become significantly ($p < 5\%$) drier relative to the historical control period (1961-1990) include Cyclades, Attiki and nearly all of northern Greece.

Within the first future period 30 year period (2021-2050), this change is less detectable, with less than 60% of the models agreeing on a statistically significant change; however, by the end of the century (2071-2100), nearly all model projections show a statistically significant decrease in the median SPI. This is particularly noticeable for KNMI and ICTP climate models.

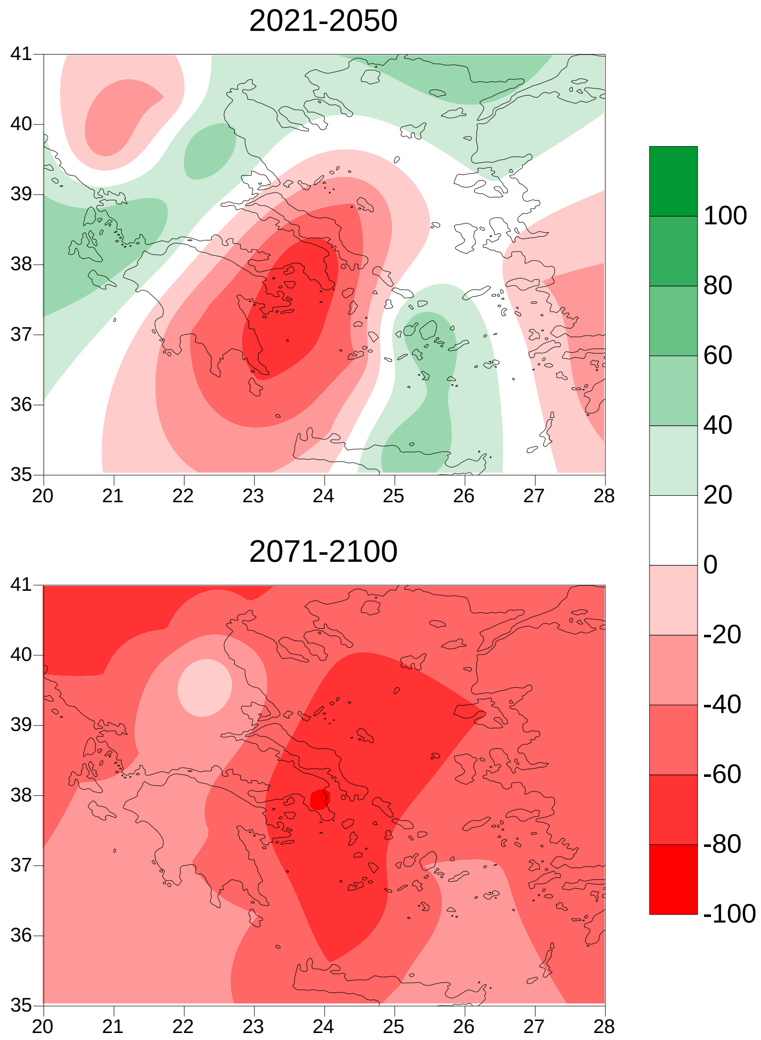

Figure 2 - Model agreement (% of models) regarding a statistically significant change in the median SPI12 for the first (top) and second (bottom) future period.

3.2. Changes in Variance (Wet and Dry Extremes)

Changes in SPI variance means whether climate model project to become more extreme (more in the extreme tails of the SPI distribution), or less extreme (more near the normal conditions). This is based on the principle that SPI is normally distributed with a standard deviation of 1. The results show that SPI variance present a slight non statistical significant increase (not shown) across Greece. This suggests an increase towards more extreme events, with higher wet SPI values and lower dry SPI values.

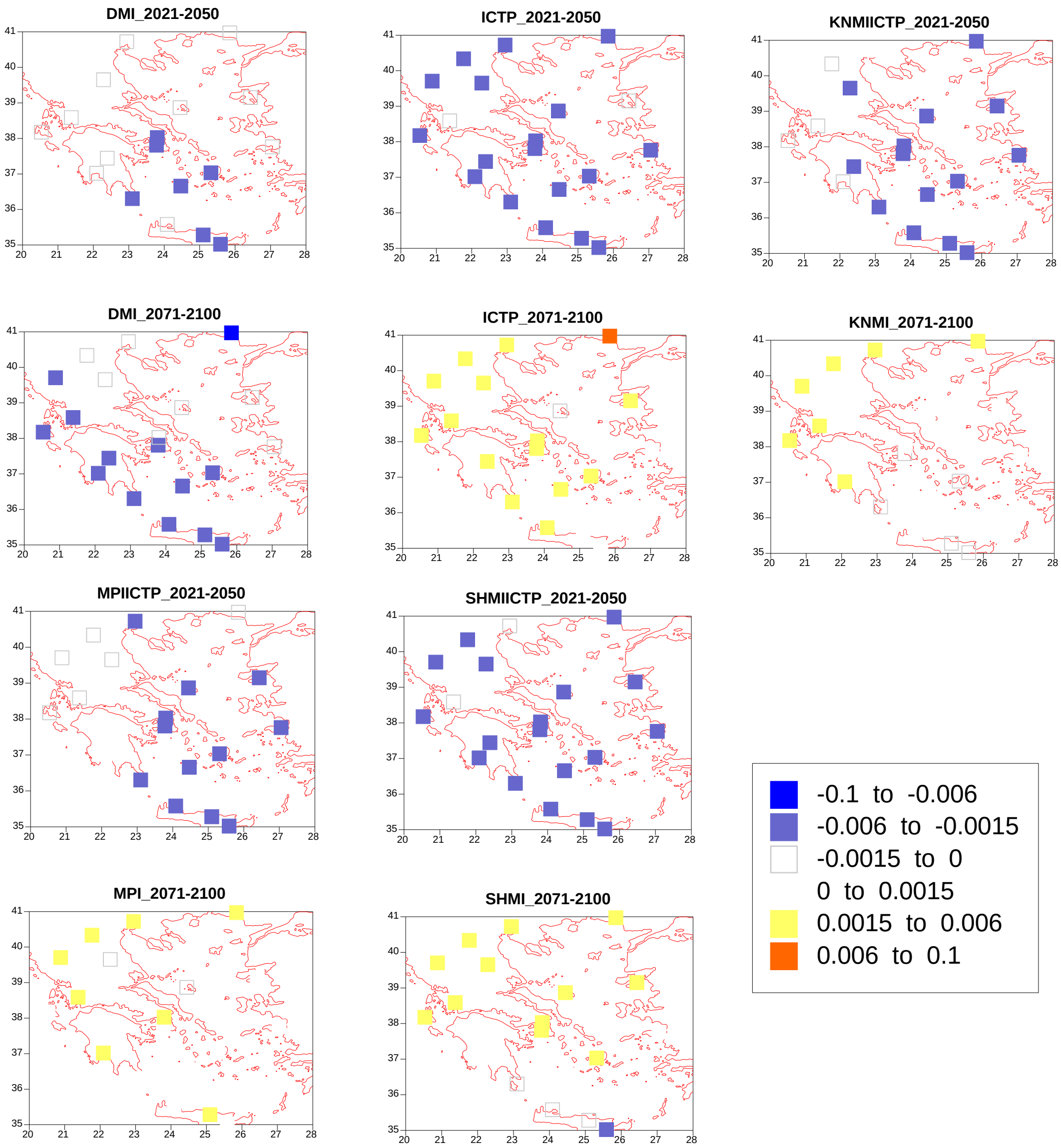

Figure 3 - Spatial distributions of the SPI trends of (a) the first future period 2021-2050 and (b) the second future period 2071-2100 for the five RCMs models. The statistically significant negative trends (grey and blue squares) indicate an increasing frequency of dry years, and the statistically significant positive trends (yellow and orange squares).

3.3. Trends of Dryness

Among the five RCMs models, those with insignificant trends (white squares) are not shown. The negative and positive trends in SPI, which represent dryer and wetter trends, respectively, were detected by calculating the slope and level of significance using the generalized least squares (Figure 3).

Trend detection using SPI indicates increasing frequency of dry years (statistically significant negative trends) for all RCMs models in the majority of the stations for the first future period 2021-2050. More than 85% of the stations (ICTP and SHMI) present statistically negative trends in the first future period. However, many fewer stations in DMI have statistically significant negative SPI trends (less than 40%,), meaning that the uncertainty of the each regional climate model results into the drought frequency. Statistically significant positive trends (increasing frequency of wet years) were found in the second future period in Greece for all RCM models, with the exception of DMI.

3.4. Future projection of drought, a case study for Athens and Thessaloniki

Figure 4 show the temporal variance of SPI12 for Athens and Thessaloniki stations for the two time period (2021-2050 and 2071-2100, respectively). It is known that SPI with high time step (more than 12 months) present seldom drought events but they last longer. Another characteristic of the SPI12 is its time lag according to the presence or absence of rainfall. Generally SPI with low time steps (3 and 6) react fast in dry and wet changes meaning that the index influenced by the monthly rainfall totals. On the other hand, indices with higher time step (12 months or longer) are not influenced by the variance of rainfall resulting into foresee less drought episodes with longer duration.

Comparing the temporal diagrams (Figure 4) of the 12-month SPI for Athens and Thessaloniki during the two future periods it is apparent that the frequency and variability of drought episodes varies from region to region and model to model. Characteristic, however, is the occurrence of dry events, in which the limits of drought episodes are clear. According to the index SPI 12, Athens show three distinct wet episodes during the first future period, at the beginning of 20s, 30s and 40s.It is noticeable that all five RCM model provide a clear dry episode at the end of the first future period. It starts after 2045 and it becomes gradually more intense in time. The station of Thessaloniki, according to the index SPI 12, shows characteristic change in the appearance of rainfall during the study periods. The beginning of the time period 2021 – 2050 could be characterized as normal for most of the models. During the start of 30s, all models present a moderate drought episode (SPI12<-2.0). For the next decades, the variance of SPI12 index is high providing no significant signal and displaying periodically dry and wet periods.

According to SPI12 results for the second future period 2071-2100, there are no major dry episodes for both stations. For Thessaloniki, the beginning of this study period is almost normal while after 2090 the years are characterized as wet according to SPI12. On the other hand, for Athens, the end of the second future period can be considered drier than Thessaloniki's one. The regional models that present the lowest variability of SPI12 (normal years) are ICTP and DMI.

4. Conclusions

This study shows the projected effects of climate change on meteorological drought at the Greek region using five RCMs forced with the ECHAM5 GCM projections. Drought is projected to increase throughout the Greek Region. These increases are due to a general shift towards a drier climate in the Mediterranean, which results in an overall increase in both moderate and severe drought frequency for the entire region, with significant increases in the number of drought events, and an increase in maximum drought duration for the Greek region.

The predictions of a generally drier Greece are similar to previous studies on SPI12 using RCMs and stations data. (Oladipo, 1985; Wilhite *et al.*, 2000). However, the analysis presented here which examines drought duration, frequency, and severity adds additional detail for both spatial resolution and drought metrics.

1st future period (2021-2050) Athens | 2nd future period (2071-2100) Athens | 1st future period (2021-2050) Thessaloniki | 2nd future period (2071-2100) Thessaloniki

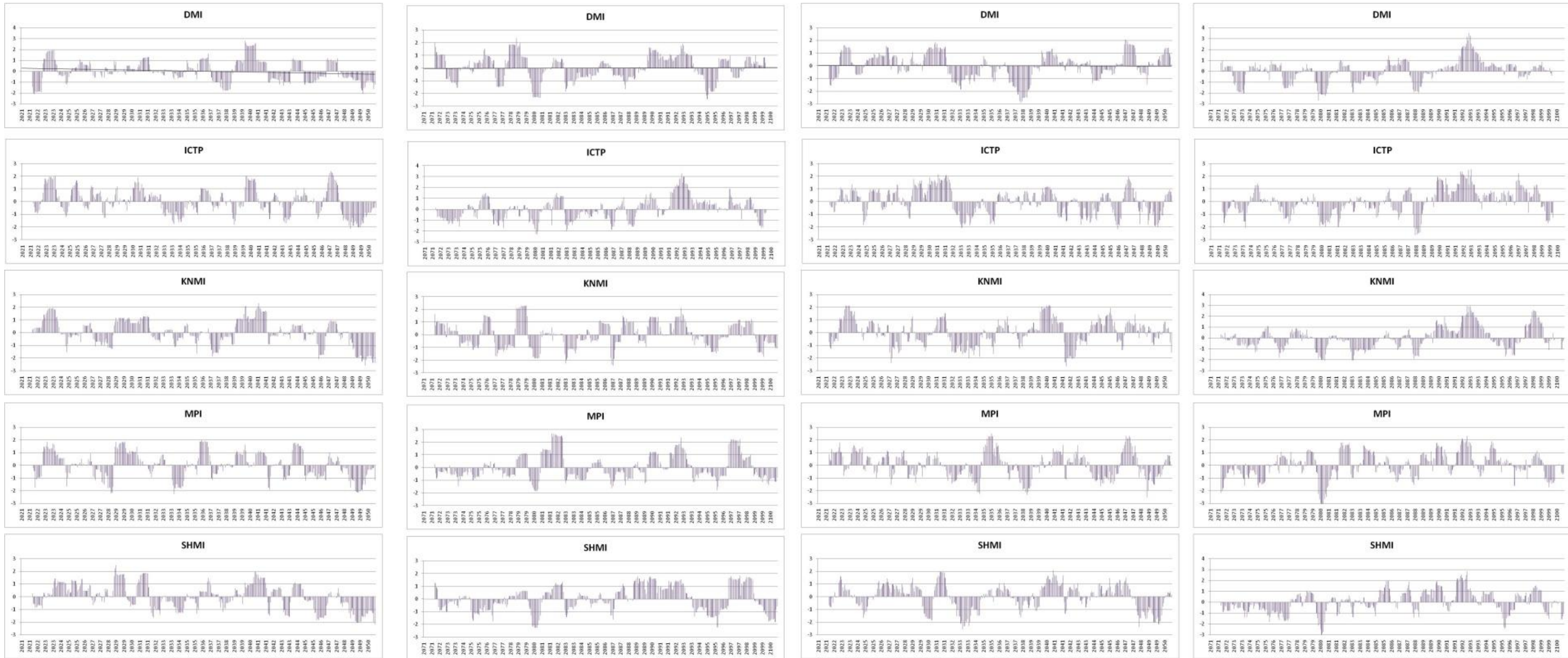

Figure 4 - SPI12 for the station of Athens and Thessaloniki, first future period (2021-2050) and the second future period (2071-2100).

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