ASSESSMENT OF DROUGHT INDICES OVER TURKEY USING DIFFERENT GRIDDED DATA

Abstract

Drought is the lack of water resources that occur in a certain region over a period of time. Along with climate change, decrease in water resources and increase in temperatures increase the frequency and severity of drought. For this reason, the analysis and modeling of drought is becoming increasingly important. There are many indices used for different purposes and calculated from different variables. Among these indices, the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) have been widely used in recent years for drought assessment and monitoring. SPI is calculated using only long-term monthly total precipitation data. SPEI differs from SPI in that it uses long-term monthly average temperature data in addition to precipitation data. By using potential evapotranspiration in the SPEI calculation, the effect of global warming on drought severity is also considered. In this study, SPI and SPEI indices are computed for 3-,6- and 12-months respectively over Turkey between 1989-2018 time period. Here, monthly average temperature and total precipitation data are taken from two different data products called ERA5-Land and NEWA-WRF. ERA5-Land is produced in higher resolution by re-analyzing the land component of ERA5, which is the fifth generation of atmospheric reanalysis of ECMWF whereas NEWA-WRF data are produced by using the Weather Research and Forecasting (WRF) model at 3 km grid spacing within the scope of New European Wind Atlas (NEWA) project that aims to generate mesoscale wind atlas over Europe. For validation, the observation data are obtained from 80 meteorological stations of Turkish State Meteorological Service (TSMS). The comparison of SPI values with observations reveals that correlations are approximately 75% for ERA5-Land and 65% for NEWA-WRF. For SPEI, these values are approximately 70% and 80%, respectively. Moreover, spatial analysis was performed for both indices over Turkey by taking ten-year averages. According to the results, SPI shows that the western and northeastern Turkey were mild drought between 1989 and 1998 while dry periods dominated whole Turkey between 1999 and 2008. In contrast to these periods, 2009-2018 exhibits more humid conditions. Unlike SPI, negative SPEI values gradually decrease in 3- to 12-montly results indicating mild drought especially for the 2009-2018 period in the central and eastern Turkey. This reveals the effect of temperature in drought analysis.

Keywords: *Drought analysis, SPI, SPEI, ERA5-Land, WRF*

1. INTRODUCTION

From past to present, the increasing population around the world has enhanced the need for water due to many socio-economic activities. However, water scarcity in some parts of the world is expected with the effect of increasing temperature and decreasing water resources along with climate change. Subsequently, when significant deficiencies in precipitation continues for a certain period of time, a natural phenomenon drought occurs. According to the American meteorological society, there are four different types of drought, namely meteorological, agricultural, hydrological and socio-economic which are defined with respect to the duration of the drought (1997). First of all, meteorological drought is a lack of precipitation due to atmospheric conditions. After a short time of meteorological drought continuation such as few weeks, agricultural drought emerges with a lack of water in the soil surface layers, and can cause serious damage to agricultural crops. Along with the prolongation of the lack of precipitation and the effect of other meteorological factors, hydrological drought arises from decreases in surface and subsurface water resources such as artificial reservoirs, lakes, groundwater. Additionally, hydrological drought continues long after the meteorological drought has ended. Finally, socio-economic drought is related to the supply-demand conditions of economic products affected by other drought processes (Heim, 2002).

In drought analyses, various indices are used to determine drought severity. These indices can be calculated using different parameters and for different time periods. Standardized Precipitation Index (SPI) is one of the frequently used and user-friendly drought indices because it uses few parameters i.e. only long-term monthly total precipitation (McKee et al., 1993). In addition to SPI, the Standardized Precipitation-Evapotranspiration Index (SPEI) takes into account also temperature data (Vicente-Serrano et al., 2010). Like SPI, SPEI has been also widely used in recent years for the assessment and monitoring of drought. There are many studies related to the indices used in drought analysis (Heim Jr. (2002), Hayes (2006), Vicente-Serrano et al. (2010), Zargar et al. (2011)). As in this study, there are several previous studies focused on drought analysis over Turkey or basins of Turkey (Komuscu (1999), Sırdaş & Şen (2003), Sönmez et al. (2005), Gumus et al. (2017)).

In this study, spatial and temporal drought analyses were performed for 3, 6 and 12 months, using SPI and SPEI indices for the years 1989-2018. In this analysis, different gridded meteorological parameters are used to calculate the drought indices over Turkey and their results are compared with the observations to find out the best representative product. Hence, drought analysis using this product might give more robust estimation of drought conditions over Turkey because of the coverage of the data over the lack of observational network. The datasets and methodology used in the study are explained in the following section. Afterwards, the results are presented and discussed in the third section. We close the paper with some conclusion and recommendations in the fourth section.

2. DATA & METHOD

2.1. Drought Indices

2.1.1. Standardized Precipitation Index (SPI)

SPI is a drought index in which designed by McKee et al. (1993) and shows water deficit for different time scales (Hayes et al. 2002). It is based on long term precipitation records and requires at least 30 years of data. Before the calculation of index, precipitation records are fitted to the gamma distribution and then normalized. After that, the mean of the dataset is set to zero (Zargar et al., 2011). As shown in Table 1, the positive values of the index demonstrate wet periods while the negative values show dry periods. One of the biggest advantages of the index is that it can be computed for 3, 6, 9, 12, 24- and 48-monthly time scales (Hayes et al. 2002) and it is only based on precipitation data. The calculation of SPI is given in Equation 2.1.

$$SPI = (P - P^*) / \sigma \tag{2.1}$$

where P: precipitation

P^*: mean precipitation

σ: standard deviation of precipitation

Table 2.1. SPI drought index categories (Hayes et al. 2002).

SPI Values	
-2.0 to and less	extremely dry
-1.5 to -1.99	severely dry
-1 to -1.49	moderately dry
-.99 to .99	near normal
1 to 1.49	moderately wet
1.5 to 1.99	very wet
2.0 to and above	extremely wet

2.1.2. Standardized Precipitation-Evapotranspiration Index (SPEI)

SPEI differs from SPI by including temperature data while measuring drought severity (Vicente-Serrano et al., 2010). The calculation of SPEI is similar to the SPI but this formula, additional to the precipitation, contains potential evapotranspiration (PET) (Eq. 2.2). By adding PET to the formula, the warming effect of climate change is included in the drought calculations and it is one of the major advantages of this index. As a first step, differences between precipitation and PET values (Eq. 2) are calculated in order to compute SPEI (Vicente-Serrano et al., 2010).

$$D_i = P_i - PET_i$$

(2.2)

The most suitable statistical distribution function based on most extreme values is Log-logistic distribution (Fisk distribution). The probability density function of Log-logistic distribution is shown as:

$$f(x) = {}^{\beta}/_{\alpha} \left(\frac{x-\gamma}{\alpha}\right)^{\beta-1} \left(1 + \left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right)^{-2}$$

(2.3)

Here, the α, β, γ are scale, shape and origin parameters, respectively and these parameters are calculated by the probability weighted moments method (Vincente-Serrano et al., 2010).

By Log-logistic distribution, the probability distribution function of D is given by Eq. 2.4.

$$F(x) = [1 + (\frac{\alpha}{x-\gamma})^{\beta}]^{-1} \tag{2.4}$$

SPEI can be calculated as standardized values of F(x) and classical approximation of SPEI is given below (Vicente-Serrano et al., 2010; Abramowitz et al., 1965):

$$SPEI = W - \frac{C_0 + C_1 + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{2.5}$$

$$\text{where } W = \sqrt{-2\ln(P)}$$

for $P \leq 0.5$, P being the probability of exceeding a determined D value, P=1-F(x). If P>0.5, P is replaced by $1-P$ and the sign of the resultant SPEI is reversed. The constants are: C_0=2.515517, C_1=0.802853, C_2=0.010328, d_1=1.432788, d_2=0.189269, d_3=0.001308. Because SPEI is standardized variable, average value is 0, and the standard deviation is 1(Vicente-Serrano et al., 2010).

2.2. Data

2.2.1. ERA5-Land

ERA5-Land is a land surface dataset from 1981 to the present. It was produced at higher resolution (9 km) and forced by ERA5 atmospheric parameters. ERA5 is the fifth-generation atmospheric reanalysis dataset of ECMWF (Muñoz-Sabater et al., 2021). This dataset was created by masking the ERA5 ocean data. The monthly total precipitation and average temperature data for the years 1989-2018 were utilized for the calculations in this study.

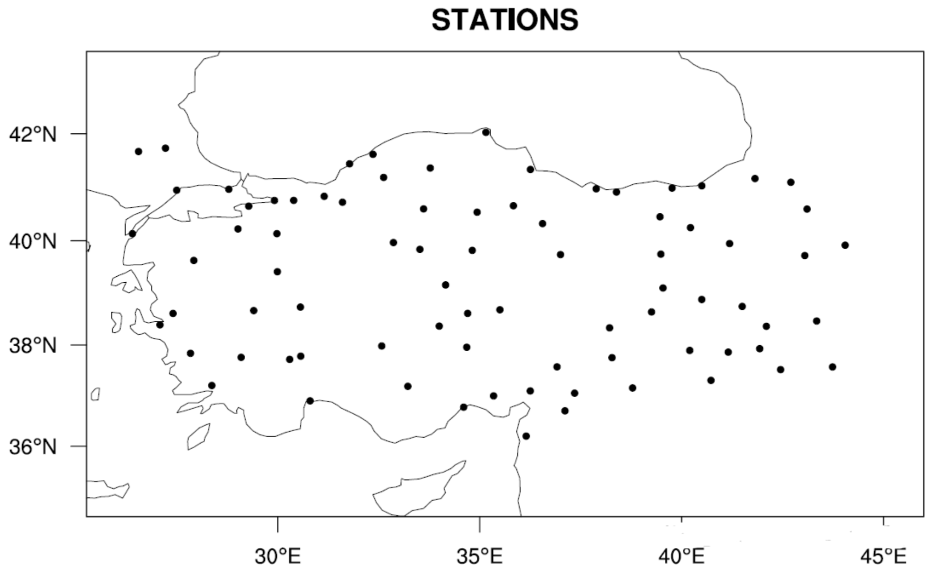
2.2.2. NEWA-WRF

NEWA stands for New Europe Wind Atlas project and in this project, it is aimed to obtain high resolution mesoscale wind conditions with new downscaling and validation methods. NEWA-WRF data were obtained by using the Weather Research and Forecasting (WRF) model with 3 km resolution within the scope of the NEWA project. The monthly precipitation and temperature data were taken as the same time period as ERA5-Land.

2.2.3. Observation Data

In this study, meteorological observation data for the years 1989-2018 were obtained from the Turkish State Meteorological Service (TSMS) stations in order to validate the data products. 80 stations were selected according to the criteria that each station should not have missing data above 20% in the relevant period. The locations of the stations used are indicated in Figure 2.1. Calculations were made by taking monthly average temperature and total precipitation data.

Figure 2.1. Station coordinates of TSMS dataset



3. RESULTS

3.1. Spatial Analysis

In this study, ten-year averages are taken in order to obtain spatial distributions of SPI and SPEI, which are computed by using ERA5-Land, NEWA-WRF and station data.

3.1.1. SPI

The average values of SPI calculated over 10-year period for ERA5-Land, NEWA-WRF and station data are shown in Figure 3.1, Figure 3.2, Figure 3.3, respectively. The columns correspond to the duration of SPI calculation while rows reveal the SPI distribution for different decades. The results illustrate that generally similar SPI patterns were obtained for all three datasets for 3, 6 and 12 month-durations. In the first period, 1989-1998, drier conditions are dominant in the north eastern and western parts of Turkey, while the southeastern, Marmara and central regions are more humid (first row of each figure). On the other hand, dry values were dominant generally in all regions between 1999-2008, except for the Eastern Black Sea region. Especially over the central area, the drought values are lower than the surroundings, around -1 in the 12-month run. Considering the period between 2009 and 2018, usually positive values predominate in the country indicating more humid conditions.

Figure 3.1. ERA5-Land SPI Spatial Distributions

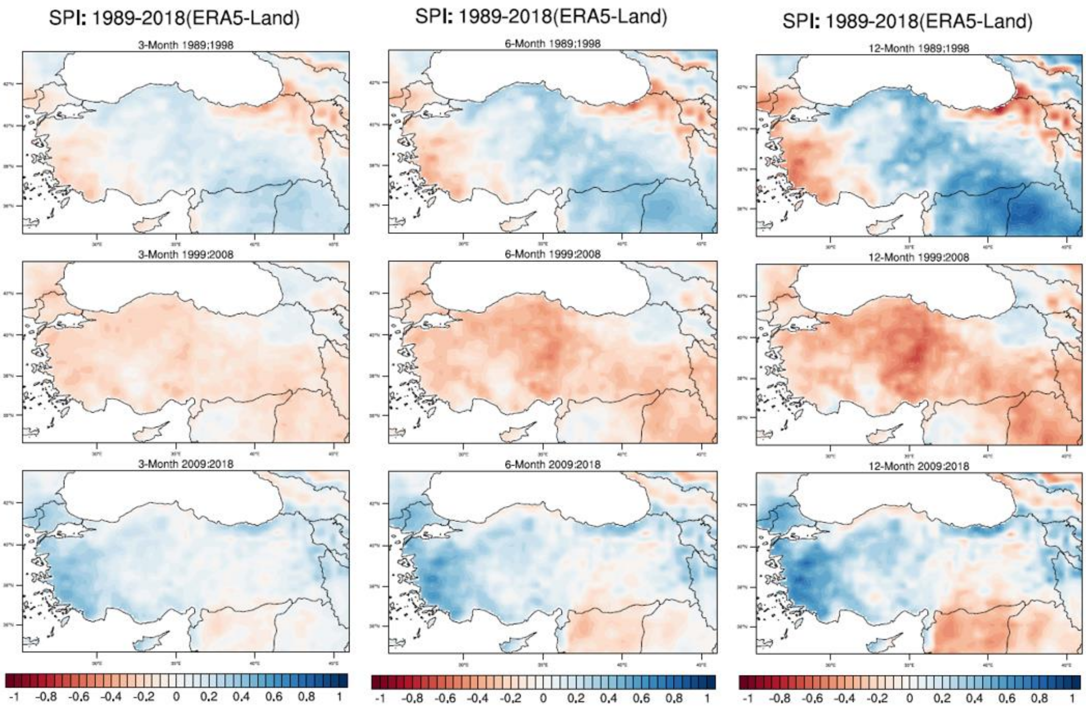


Figure 3.2. NEWA-WRF SPI Spatial Distribution

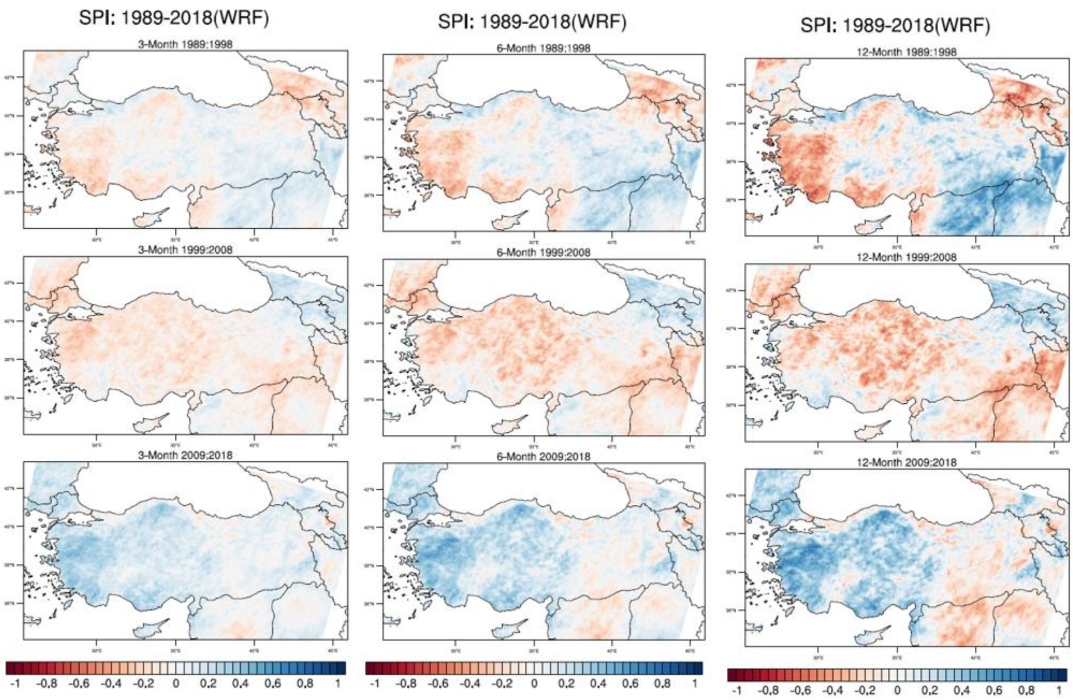
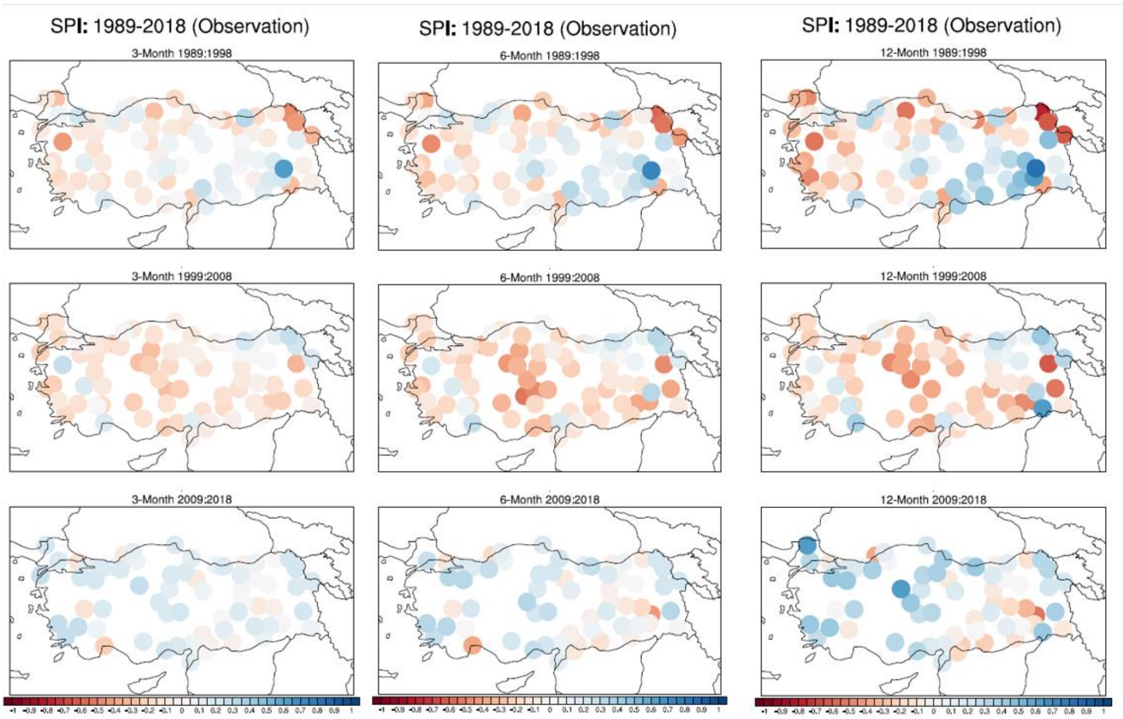


Figure 3.3. Station Data SPI Spatial Distribution



3.1.2. SPEI

As with SPI, SPEI was calculated for all datasets used in the study. The 10-year average values of SPEI for ERA5-Land, NEWA-WRF and station data are shown in Figure 3.4, Figure 3.5 and Figure 3.6, respectively. General structure of the figures is similar to the SPI figures. Generally similar results were obtained for all three data sets. When the first period, that is, between 1989 and 1998, is examined, dry values are dominant in the northeastern and western regions of Turkey, while the southeast, Marmara and central regions are more humid. This humidity condition showed higher values than the SPI index. On the other hand, dry values were dominant in all regions, except for the Eastern Black Sea region, between 1999 and 2008. Similar values were obtained for SPI and SPEI in the second time period. Especially in the central Anatolia, the drought values are lower than the surrounding area, around -1 in the 12-month runs. The biggest difference between SPI and SPEI occurred for the period between 2009-2018. While there are quite humid values in the SPI maps (Figures 3.1, 3.2, 3.3), the SPEI index values obtained in the center and east of Turkey indicate that dry values are in the majority.

Figure 3.4. ERA5-Land SPEI Spatial Distribution

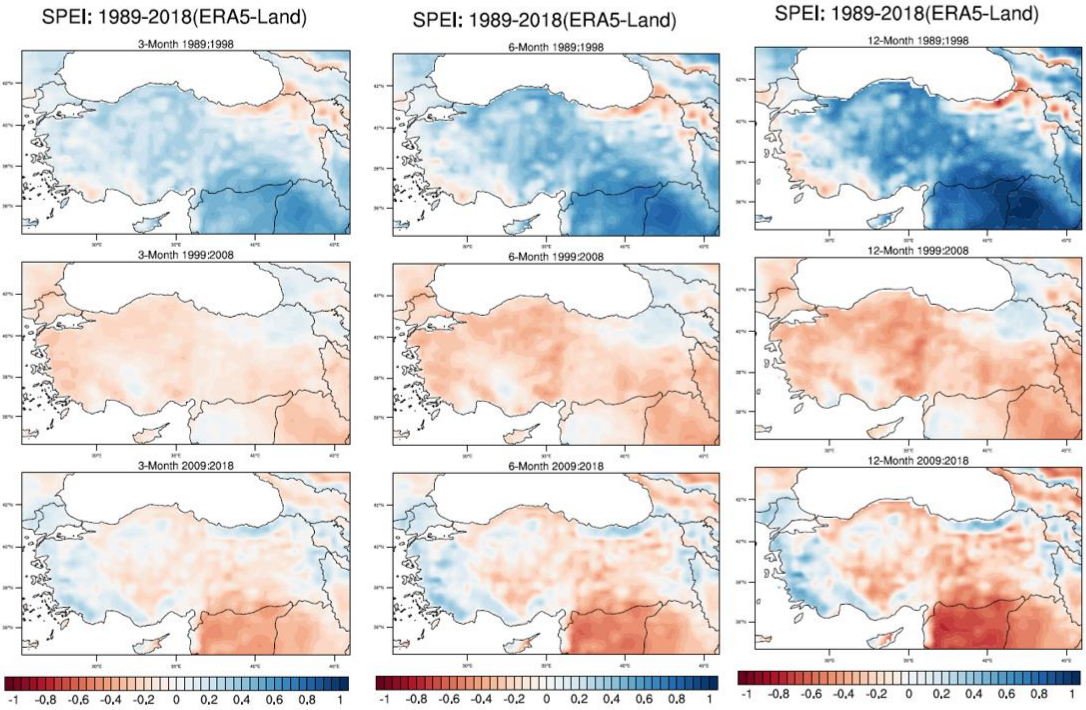


Figure 3.5. NEWA-WRF SPEI Spatial Distribution

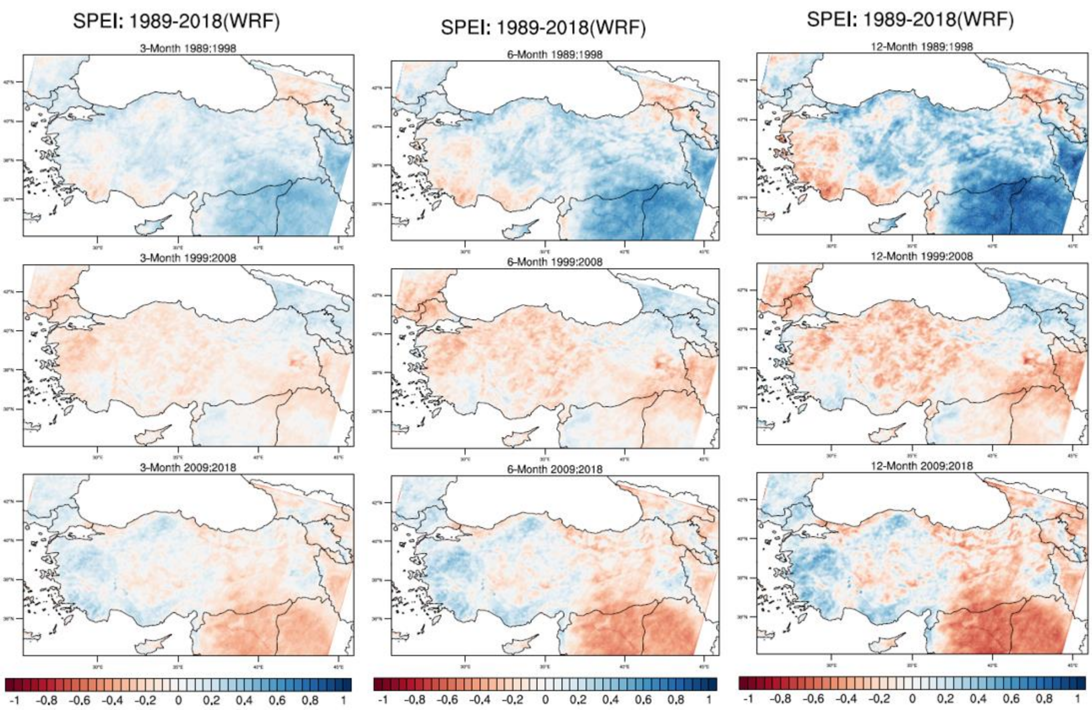
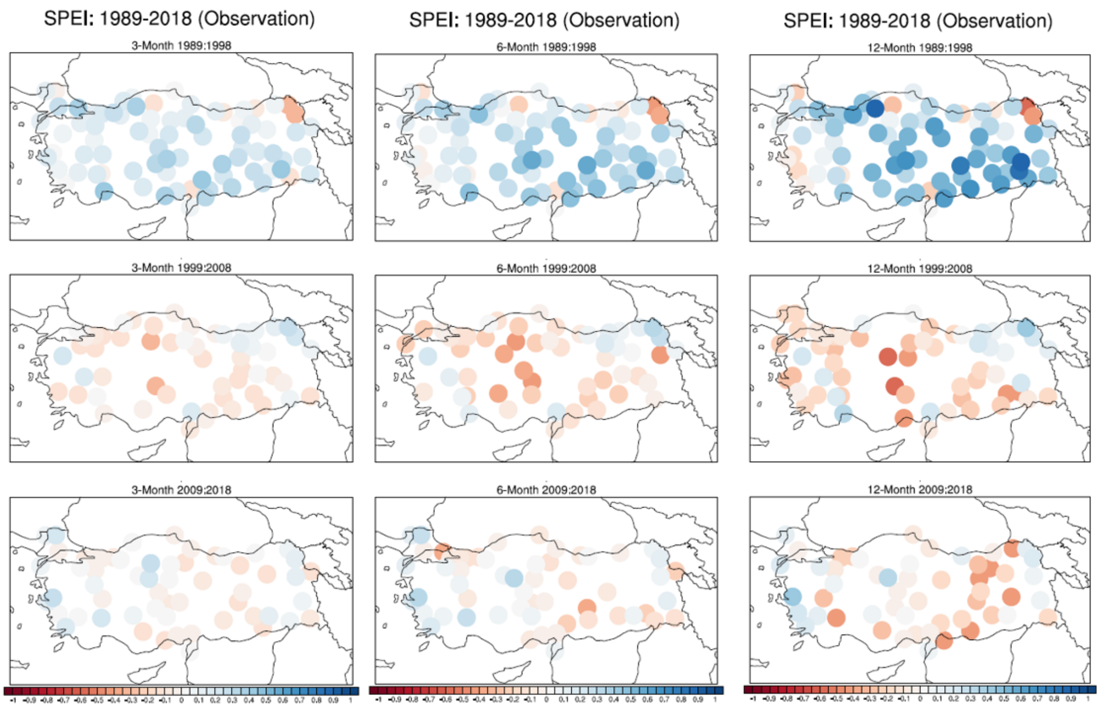


Figure 3.6. Station Data SPEI Spatial Distribution



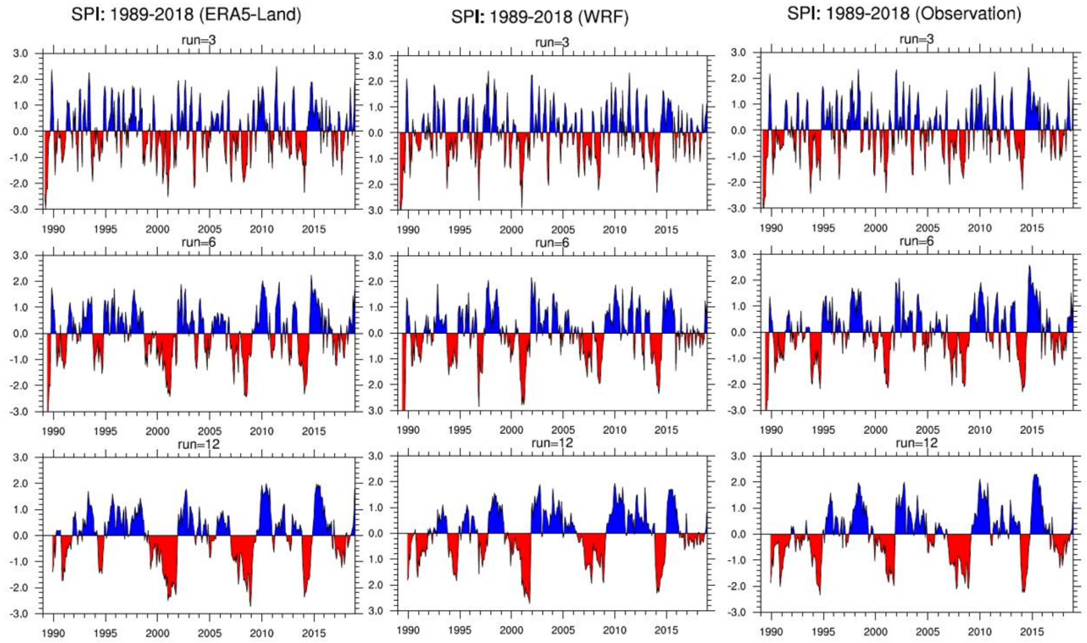
3.2. Temporal Analysis

In this study, to examine the temporal variation of drought indices and to estimate the general tendency of drought conditions over Turkey, the index values close to the station observations are collected for each data set and then the average of these index values are calculated. So that, we analyzed the performance of the different gridded product to reveal the drought conditions and their tendencies by comparing these results with the observations.

3.2.1. SPI

The temporal variations of the averages of the 3-, 6- and 12-months index values of the SPI are illustrated in Figure 3.7. Positive, that is, humid values, are shown in blue, and negative, that is, dry values, in red. Values less than -1.5 in the figures corresponds to 'very dry' conditions. 12-month runs in Figure 3.7 indicate that very dry values are calculated for all three datasets for the period 2008-2009. While the products give extreme dry values between 2000-2002, very dry values are obtained in the station observation. In 2014, extreme dry values were obtained in both products and the observation.

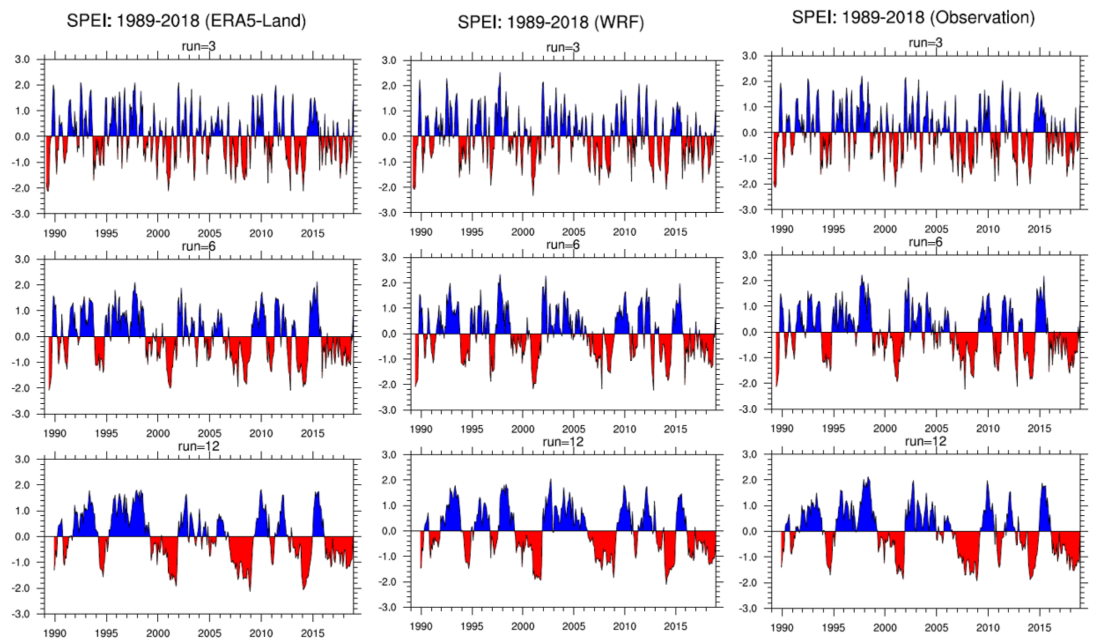
Figure 3.7. SPI Temporal Distributions



3.2.2. SPEI

Second temporal analysis made by taking the average of the 3, 6 and 12-month index values of the SPEI (Figure 3.8). As in SPI, values less than -1.5 on the graphs mean 'very dry'. 12-month runs in Figure 3.8 points out that very dry values were calculated for all three data sets for the 2000-2002 and 2008-2009 periods. In 2014, extreme dry values were obtained in both products and observation. Although drought periods in SPEI index are similar to SPI, drought durations are longer than SPI. In addition, SPEI is lower, which means drier values, compared to SPI between 2016-2018. The reason for these situations is the calculation of potential evapotranspiration with temperature data in the SPEI calculation.

Figure 3.8. SPEI Temporal Distributions



4. CONCLUSIONS & RECOMMENDATIONS

In this study, spatial and temporal analysis of SPI and SPEI are performed over Turkey for between 1989-2018. 3-, 6-, and 12-month runs are calculated for SPI and SPEI by using two different data products named ERA5-Land and NEWA-WRF. For the validation of these data, observation data from TSMS stations were utilized. When the spatial analyzes are examined, dry values were obtained for both indices in the western and northeastern of Turkey for the period 1989-1998. In the second period, 1999-2008, dry values are dominant in general. On the other hand, the significant differences between SPI and SPEI are more evident after 2009. In fact, while more humid values are observed in the majority of SPI, there are dry values in central and eastern Turkey in SPEI. There are two important differences between SPI and SPEI in temporal analysis, especially while considering 12-month runs. First of all, the duration of dry periods is longer in SPEI than SPI. Secondly, the drier values after 2016 were obtained in the SPEI compared to the SPI. These differences, which emerged for both analyzes, indicate that taking into account the temperature in the drought analysis creates major changes in the results.

As a result, spatial and temporal drought areas and years over Turkey were examined with model and observation data. By examining two different indices, the importance of temperature in drought analysis has been revealed. Considering that temperatures continue to increase with the effect of climate change, it is important to make plans in this direction by working on drought analysis studies for future scenarios, especially in countries like Turkey where agriculture has a significant share in the economy.

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