Solar Cycle Forcing on Kurdistan-Iraq Temperature

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Abstract:

The energy transfer from the sun to the atmosphere is one of the primary drivers of the weather. The Earth climate is strongly affected by the amount of solar radiation emitted by the sun, which changes with solar activity. The search for cyclicity in the climate record can resolve some complexities of the atmospheric system. Periodicities in the sun spot number time series, annual, seasonal temperature time series have been studied visualising the data for 63 years spanning over the period 1948-2011. The temperature series is obtained from NCAR-NCEP reanalysis data centre. The sunspot number and temperature series, where subjected to spectral analysis by multitaper method to investigate the possible periodicities exist in all series. Several periodicities in the band 10.5-12.5 years are detected in annual and seasonal temperature where they are related to solar cycle. The temperature at Kurdistan is negatively correlated with the length of the solar cycle. The North Atlantic oscillation also affects the temperature of the region through 3.7 years periodicity.

Key words: Sunspot Number, Solar Cycle, solar cycle length, Multitaper Method, The National centre for Environmental Prediction and National Centre for Atmospheric Research, North Atlantic oscillation.

1. Introduction

The climate of the region is semi-arid continental, hot and dry in summer, cold and wet in winter, with large temperature differences between day and night and between winter and summer. Spring and autumn are short in comparison to summer and winter. The highest temperature is in Jul; the lowest temperature is in Jan for Kurdistan- Iraq region (Fig. 1). The detection of oscillation in precipitation time series yields important information for understanding the climate.

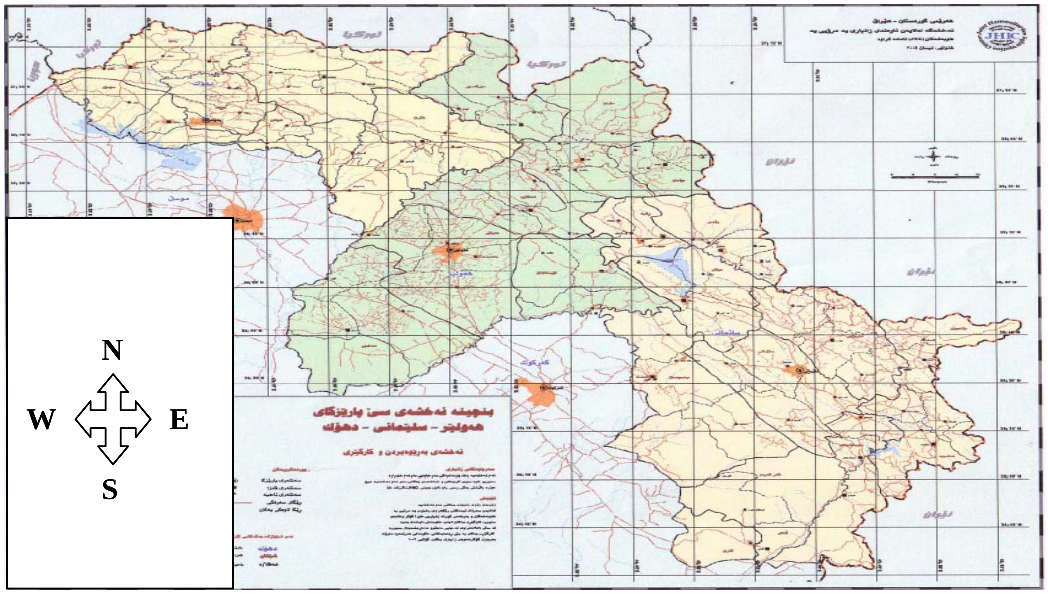

Fig. 1: Kurdistan-Iraq region map (the study area) [1]

2.1 Solar Cycle and Sunspot Number

Chinese astronomers in 1611 were the first who reported on dark spots visible on the Sun called sunspot. The number of sunspots changes with an 11-year period. Today its known that all solar activity phenomena are related to sunspots and thus to magnetic activity. To measure the solar, activity the sunspot numbers were introduced:

$$R=K\,(10g+f) \qquad (1)$$

Here g denotes the number of sunspot groups and *f* the number of spots. The K factor is a correction which takes into account the different instruments used for the determination of R [2].

Sunspots are of a large structure with typical diameter in the range of 10000 to 20000 km that are strongly magnetized (around 3000 G in the central regions). They are visible on the solar surface as dark features with a dark core called the umbra with a much lower temperature (around 4000 K) than the ambient atmosphere and surrounded by a lighter region called the penumbra. Sunspot is dark because it is cooler than the surrounding photosphere [3]. The number of sunspots and sunspot groups (sunspot number) present on the solar surface changes with time and exhibits a cyclic behaviour with an approximately 11-year period. The amplitude of the cycle (often called the strength of the cycle) varies from one cycle to another. Although the sun is separated by 150 million km from the Earth, thus it is inextricably linked to the Sun by an energy flow that both sustains and imperils life [4]**.** The Sun undergoes a period of very few sunspot numbers of the order of 10, called the solar minimum to a period of sunspot numbers of the order of 100, called the solar maximum. The period between the solar minima or between the maxima is about 11 years [5].

Many scientists studied the relation between the sunspot number, solar cycle length and surface temperature. A systematic study by Solheim et al. of the correlation between Solar Cycle Length (SCL) and temperature lags in 11-year intervals for 16 data sets, revealed that the strongest correlation took place 10–12 years after the mid time of a solar cycle, [6].

Rajamoorthy et al. studied the influence of the solar activity on the surface temperature of the Earth, particularly in Northern Hemisphere, Southern Hemisphere, Global, and Tropical region temperature. The mean temperature data of 130 years and sunspots data were taken into account. From the correlative and regression analysis they have found the results that there is a strong connection between solar maximum of solar cycle and temperature of the Earth [7].

Friis-Christensen and Lassen compared sunspot numbers with the Northern Hemisphere land temperature anomaly; they found a better correlation between the SCL and the temperature anomaly than with the number of sunspots, in the sense that shorter sunspot cycles indicated higher temperatures, also they concluded by stating, 70-90 year oscillations in global mean temperature are correlated with corresponding oscillations in solar activity [8].

Jerzy Boryczka and Maria stopa-Boryczka determined the periodicity and trend in air temperature and precipitation in Poland in the time period 18^{th} -19^{th} centuries with forecast for the 21^{st} century. The spectrums and cycles of temperature, NAO index and temperature and solar activity were determined using regression sinusoids, it concluded that the close-to-11 year periods of temperature and precipitation are undoubtedly caused by the 11-year cycle of solar activity [9].

Butler, found good correlations between the temperature measured at Armagh Observatory in the period 1844–1992 and the number of sunspots smoothed with the 1-2-2-2-1 filter [10].

2.2 North Atlantic Oscillation (NAO)

NAO is one of the largest teleconnection patterns in the Northern Hemisphere. It describes a large-scale oscillation in atmospheric mass between the sub-polar region near Iceland and the subtropical Atlantic, swinging from one phase to another and producing large changes in the mean wind speed and direction over the Atlantic, the heat and moisture transport between the Atlantic and the neighbouring countries, the intensity and the number of storms, their path, and their weather. Agriculture harvests, water management and energy supply are directly affected by NAO [11].

The NAO exists and acts in all seasons but it is most pronounced during winter months (Dec., Jan., Feb. and Mar.) because an increased sea-air temperature

contrast and the atmosphere is most active dynamically and perturbation grow to their largest amplitudes [12]. The NAO is quantified by the NAO index which represents both the phase and the amplitude of the NAO. NAO index data used in this study is found by Jones (1997) based on the difference between standardized SLP from Gibraltar and Reykjavik (Iceland) available, at:
http://www.cru.uea.ac.uk/~timo/datapages/naoi.htm

2.3 Data source:

The longest temperature series is obtained from the NCEP _NCAR reanalysis data centre. Its spanning over the period 1948 -2011 for 62 years. The National centre for Environmental Prediction (NCEP) and national centre for atmospheric research (NCAR) have been cooperated in project (denoted reanalysis) to produce a retroactive record of more than 50 years of global analysis of atmospheric fields in support of the needs of the research and climate monitory communities, this effort involved the recovery of land surface, ship, rawinsond, pibal, air craft, satellite and other data. These data were then quality controlled and assimilated with a data assimilation system kept unchanged over the reanalysis period [13].

Monthly average temperature is directly obtained from the NCEP-NCAR reanalysis, provided by NOAA/OAR/ERL physical science division from its web site at:
http://www.esrl.noaa.gov/psd/cgibin/data/timeseries/timeseries1.pl.

The data are reported with 2.5^{o} latitude-longitude geographic resolution. The studied region is Kurdistan region located in the girded box of NCEP/NCAR reanalysis at longitude range 42.5^{O} -45^{O} and latitude range 37.5^{O} -35^{O}.

The reanalysis data are actually the output of global weather forecasting model operated in a mode that continuously assimilates observed data from the world wide network of meteorological observations. The model interpolates meteorologically coherent values of temperature into those grid boxes where there are no actual measurements [14].

The sunspot data is selected in the same period of temperature and is obtained from NASA web page at: http://solarscience.msfc.nasa.gov/greenwch/spot_num.txt

2.4 Spectral analysis technique:

Most time series like rainfall, temperature series and sunspot number exhibit some periodic patterns that can roughly be represented by some of the harmonics. There is periodic recurrence of meteorological phenomenon at many intervals, ranging from a few hours to hundreds of years, it is an attempt to demonstrate periodicities of use in long range forecasting [15]. Spectral analysis is the separation of a signal into different frequency components, it is essentially a modification of Fourier analysis so as to make it sutible for stochastic rather deterministic function of time [16].

2.4.1 Multitaper Method (MTM)

The Multitaper method of spectral analysis provides a novel means for spectral analysis and a signal reconstruction of a time series whose spectrum may contain both broadband and line components [17]. In this method the data sequence to be analysed is multiplied by a series of weights called tapers; the result is then Fourier transformed (using fast Fourier transformation) and squared to obtain the estimated power spectral density [18]. These tapers minimize the spectral leakage (power leakage is artificially high power estimates at frequencies away from the true peaks frequencies) outside a frequency with the half band width also this method attempts to reduce the variance of spectral estimates by using a small set of tapers [19].

MTM can provide estimates of both the line components and the continuous background of the spectrum. Once the tapers $w_k(t)$ are computed for a chosen frequency band width, the total power spectrum S_X can be estimated by averaging the individual spectra given by each tapered version of the data set. We call $\hat{S}_k(f) \equiv \left|Y_k(f)\right|^2$ the k the eigenspectrum, where Y_k is the discrete Fourier transform (DFT) of {X(t) w_k(t): t =1,…., N}.The high resolution multitaper spectrum is a weighted sum of the *K* eigenspectra,

$$S_r(f) = \frac{\sum_{k=1}^{k} \mu_k \left|Y_k(f)\right|^2}{\sum_{k=1}^{k} \mu_k} \qquad (2)$$

The relative weights μ_k on the contributions from each of the *K* eigenspectra can be adjusted further to obtain a more leakage-resistant spectral estimate, termed the adaptively weighted multitaper spectrum,

$$S_w(f) = \frac{\sum_{k=1}^{k} b_k^2(f)\mu_k \left|Y_k(f)\right|^2}{\sum_{k=1}^{k} b_k^2(f)\mu_k} \qquad (3)$$

The number k of taper used should be less than 2p-1 in any application of MTM where p is a suitably chosen integer. The MTM has been widely applied to problems in geophysical signal analysis including analysis of instrumental data on the atmosphere and ocean [17]. This method offers some unique features: a high resolution and statistical confidence level that are independent on the spectral power. According to Park et al. (1987), only the first S=2p-1 tapers are usefully resistant to spectral leakage, where p is the time- frequency band width parameter. In the context of climate studies, the choice P=2 and hence S=3 provides a good comprise between resolution appropriate to resolve climate signals and the variance of the spectral estimate [20].

3. Results and discussion

The cycle length is obtained during maximum and minimum periods from the difference between the subsequent and previous maximum/minimum points. The sun exhibits a periodic cycle of about 11 year cycle and figure 2 shows the sunspot number over the period 1948-2011 which includes the solar cycle from 19 to solar cycle 23.

The spectral analysis using Multitaper method is applied on applied annual sunspot number, winter, spring, summer, autumn and annual temperature series of Kurdistan region for 63 years over the period 1948-2011 to detect the periodicties in these time series, Thus the association between the sunspot number with seasonal and annual temperature of study area can be found.

Figure 3 shows the spectral analysis of annual sunspot number time series, it is clear that the existing periodicities are 3.47 years above the median level, 4.9 year above 95 % significant level and the band 10.2-12.4 years above 99% significant level which a strong harmonic peak. The last frequency band is important due to solar cycle activity in the spanning period 1948-2011. Figure 4 reveals the power spectra of winter temperature series and consists of the following periodicities: 2.68 years above 99% significant level, 3.2-4.16 years above 90% significant level, 11.11 years above median level and 20.4 year above median level. From the periodogram of Kurdistan spring temperature as in figure 5, we get several cycles as: 2.12-3.77 above median level, 11.23 years below median level and 4.54-5.55 year above 90% significant level and 50 year above 95% significant level. Summer temperature spectral analysis in figure 6 demonstrates many periodicities: 2.2-2.3 years band, 3.44 years, 4.7 years, 10.8 years and 28.5 above median level.

The power spectra of Kurdistan autumn temperature from figure 7 illustrate the following periodicities: 2.63-2.98 years band above 90% significant level, 4.34-5.4 year above median level, 11.6 years above median level and 29.9- 45.8 years band above 95% significant level.

The spectral analysis of Kurdistan annual temperature from figure 7 contains the following periodicities: 2.77 years above 95% significant level, 3.77 above 90% significant level, 11.6 year above median level and 29.8-45 years band above 90% significant level.

To find the relation between the solar cycle length and Kurdistan surface temperature, the linear regression is calculated as in figure 9 and is given by the equation:

Annual temperature (^{o}C) = 18.5362 - 0.2765 Solar cycle length (year)

Since the correlation between solar cycle length and Kurdistan surface temperature is - 0.924 and significant at the level of 0.05, it indicates that along cycle length lead to relatively low temperature in the next cycle and short cycle length lead to relatively higher temperature over the study period which included SC 19 to SC23.

The North Atlantic oscillation is one of the largest teleconnection pattern affecting the climate of the northern hemisphere. The NAO index series also exhibits some periodic cycles in the given period of temperature series. A cycle of 2 years above 90% level, 2.7 above 99% level which is a strong harmonic peak, 3.7, 8.7, 10.6, and 20.8 years above median level are detected from applying Multitaper method on the NAO index series as in figure 10.

3.1 Association between Kurdistan Temperature with Solar Cycle and NAO:

From the previous part it appears that the periodicities 11.11, 11.23, 10.8, 11.6, 11.6 years of winter, spring, summer, autumn and annual Kurdistan temperature respectively are related to solar cycle in the 10.5-12.5 years band.

The periodicities 3.7 year in 3.2-4.16 band in winter temperature, 3.77 years in spring temperature and 3.77 years in annual temperature series are related to the NAO in the periodicity of 3.7 years.

3.2 Trends in Annual Temperature

Annual temperature is found by averaging the temperature from Jan. to Dec. over the period 1948-2012, the linear regression analysis is found for annual temperature as in figure 11. Tow distinct trends are detected in annual temperature time series, the first is down ward trend at the period 1948-1972 with average temperature decrease 0.679 ^{o}C/decade since the regression equation is given by:

annual temp. (^{o}C) =149.1401-0.0679 year

The second trend is upward spanning over the period 1973-2011 with an average increase 0.492 ^{o}C/decade where the regression is given by:

annual temp. (^{o}C) = -82.408+0.0492 year

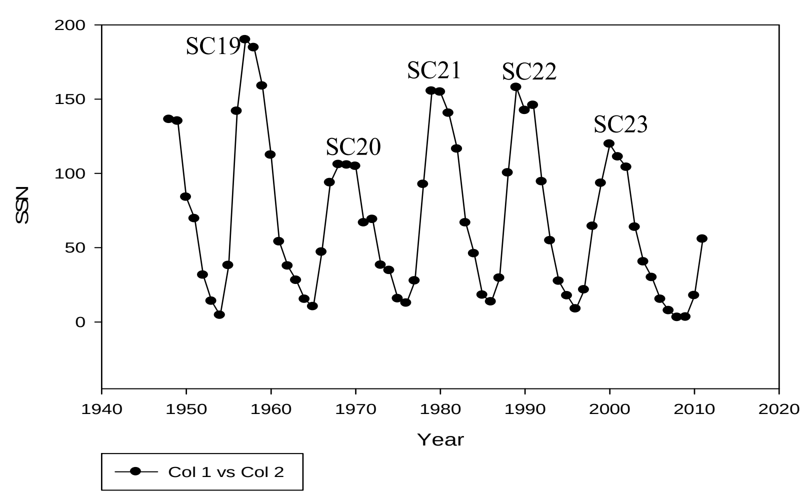

Fig. 2: temporal variation of annual sunspot number

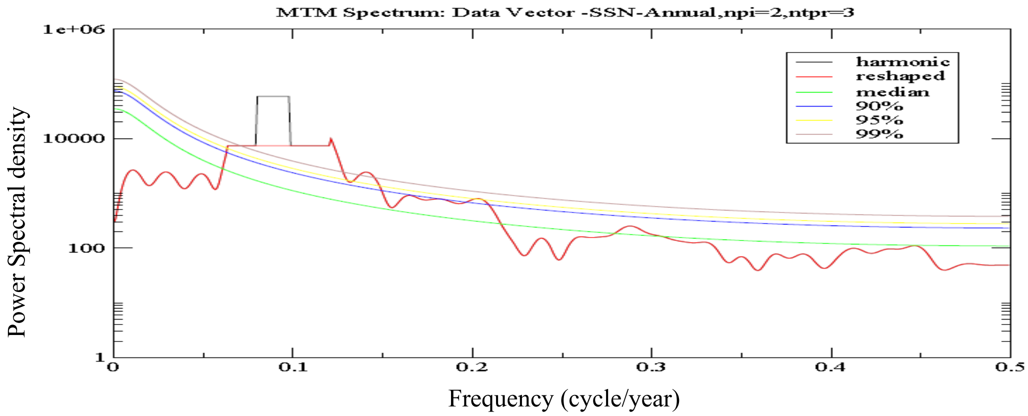

Fig. 3: Power spectra of sunspot number series by multitaper method

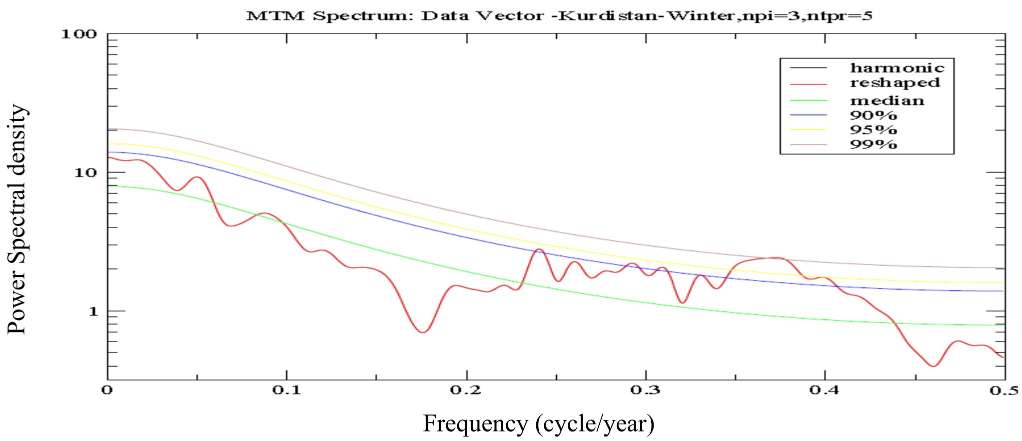

Fig. 4: Power spectra of Kurdistan winter temperature series by multitaper method

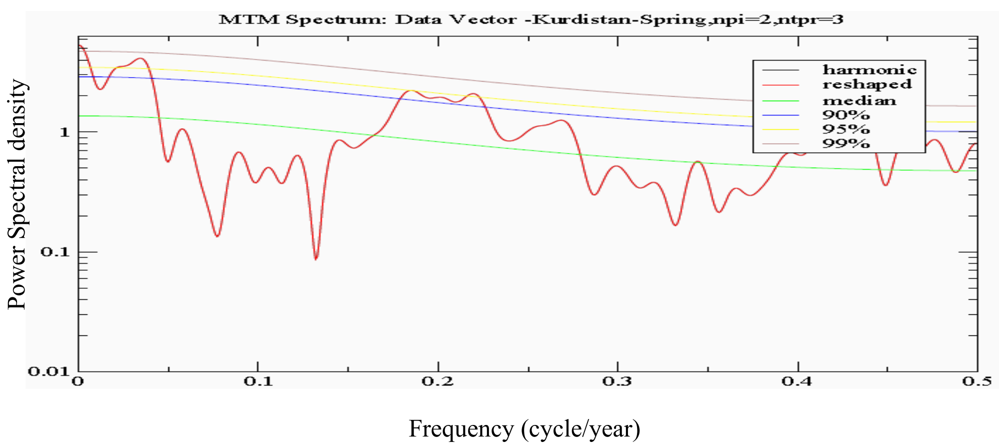

Fig. 5: Power spectra of Kurdistan spring temperature series by multitaper method

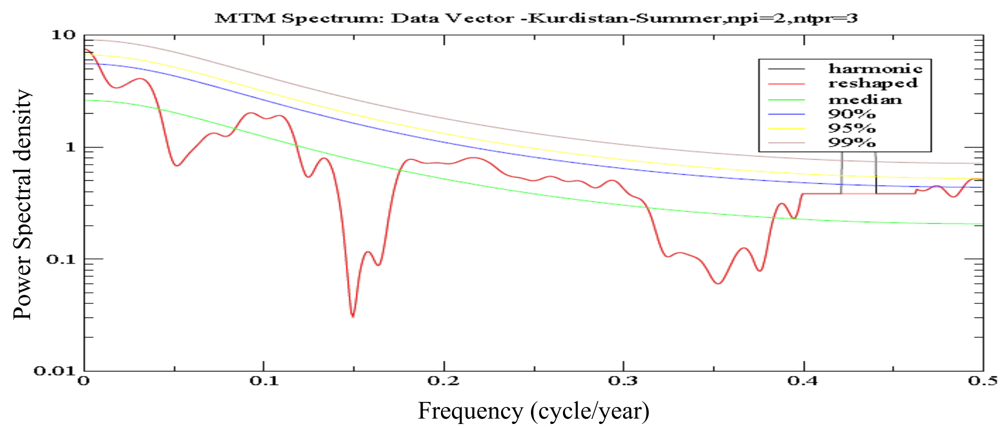

Fig. 6: Power spectra of Kurdistan summer temperature series by multitaper method

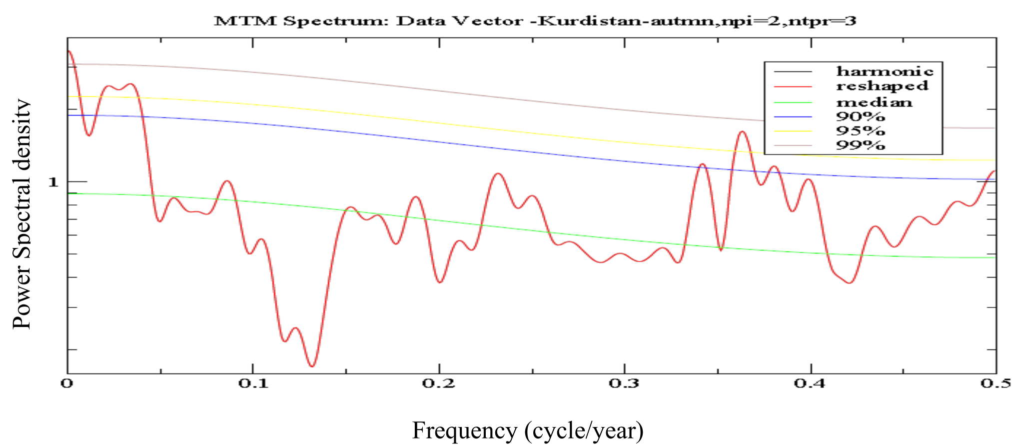

Fig. 7: Power spectra of Kurdistan autumn temperature series by multitaper method

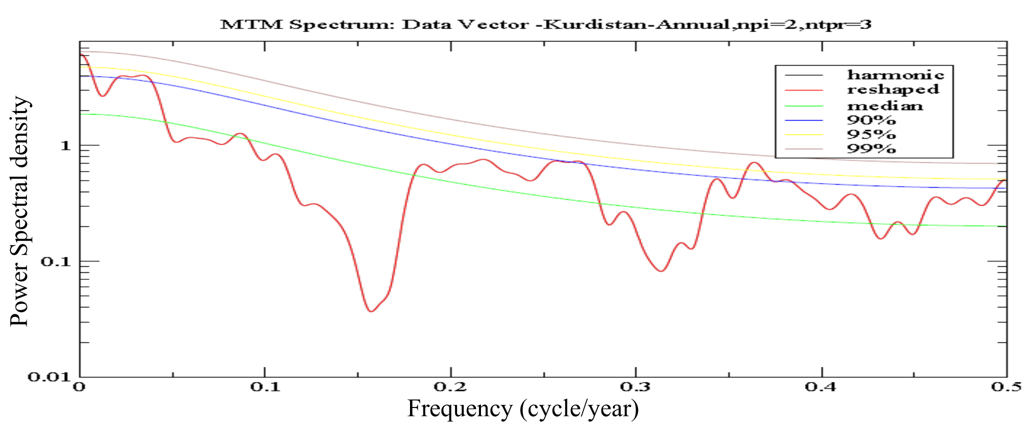

Fig. 8: Power spectra of Kurdistan annual temperature series by multitaper method

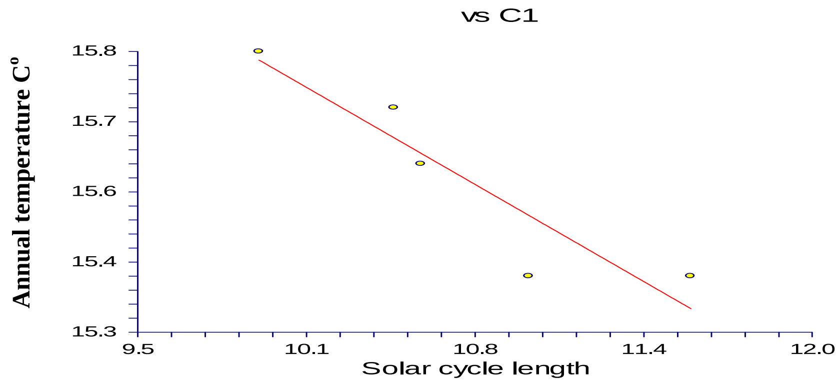

Fig. 9: Annual temperature regression with solar cycle length

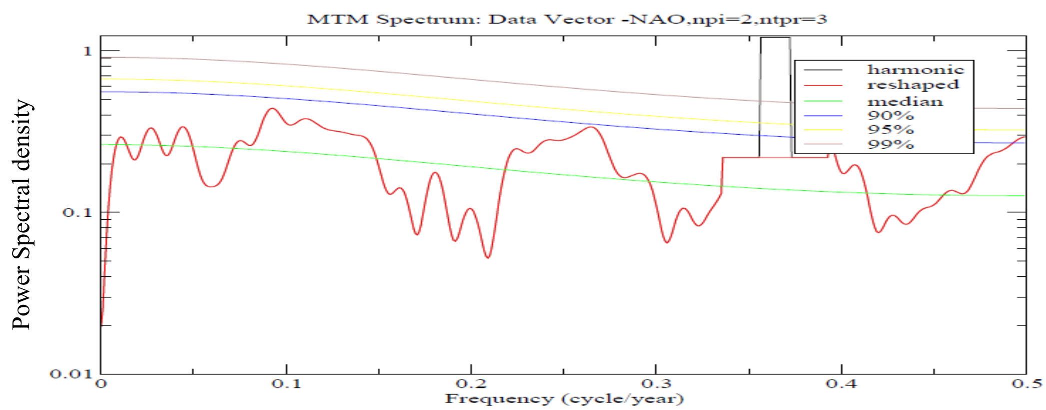

Fig. 10: Power spectra of NAO index series by multitaper method

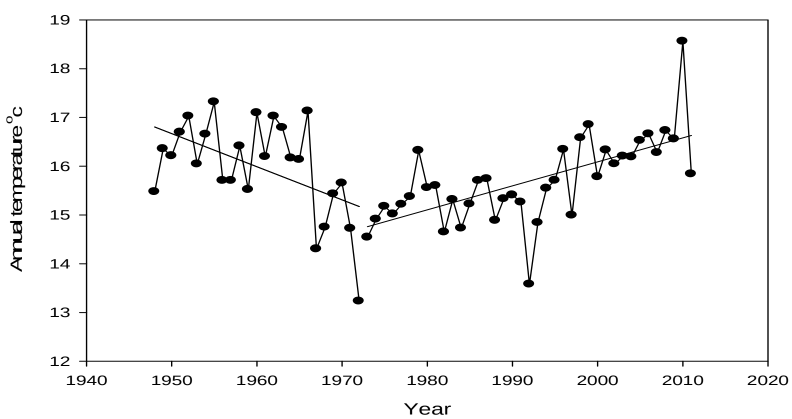

Figure 11: Annual mean temperature at Kurdistan 1948-2011

4. Conclusions:

I. Several cycles of annual sun spot number, Kurdistan annual and seasonal (winter, spring, summer and autumn) temperature are detected via the analysis of power spectra of these series, the solar signal (10.2-12.4 years) affects Kurdistan temperature and cannot be ignored through the following cycles: 11.11 years in winter, 11.23 years in spring, 10.8 years in autumn and 11.6 years in the annual temperature of the region, thus sun spot number affect the annual and seasonal temperature of the study region.

II. The regression equation of annual temperature against solar cycle length is given by:

Annual temperature (^{o}C) = 18.5362 - 0.2765 Solar cycle length (year)

This equation is useful to forecast the temperature for a given solar cycle length and simply providing an estimate of the rate of future occurrence.

III. From the correlative analysis we have found an inverse relation between solar cycle length and annual temperature of Kurdistan region, since the correlation coefficient is -0.925 and significant above 0.05 level.

IV. NAO index series is spectrally analysed and several cycles are found, these cycles affects Kurdistan temperature through 3.7 year cycle which occurs in winter, spring and annual temperature of Kurdistan since autumn and summer temperature are not influenced by NAO activity.

V. Regression analysis of annual temperatures shows two distinct trends, first is downward trend with an average decrease 0.679 ^{o}C/decade in the period 1948-1972 followed by an upward trend with average increase 0.492 ^{o}C/decade at the period 1973-2012. The uptrend behaviour is related to solar cycle activity in the last two decades and the global warming due to increase the green house gases.

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