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Solar and Geomagnetic activity effects on Egypt's climate

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ABSTRACT

We had investigated the effects of solar/geomagnetic activities on the surface air temperature of Egypt. We used the monthly sunspot numbers, solar flare and flux, total solar irradiance and geomagnetic disturbances as solar and geomagnetic activity indicators. We considered monthly Egypt surface air temperature (ESAT) throughout the period 1881-2009, which covers 12 solar activity cycles. We found a negative correlation between ESAT and solar geomagnetic indices, as well as a positive correlation with total solar irradiance for the entire data set. We found that the sign of the correlation between ESAT and Rz depends on North–South sunspot area, being positive when the Northern solar hemisphere is predominantly more active, and negative when more active is the southern hemisphere except for the cycle 13. The power spectra analyses have been applied to obtain the spectrum-cyclic behavior of ESAT, as well as for other parameters. The most pronounced power peaks were found around periods of 25.6, 8.0, 5.6, 4.1, 2.7, 2.3 years, indicating a remarkable role of solar/geomagnetic activities on Egypt's temperatures. We concluded that the signature of solar activity effect may exist on surface air temperature of Egypt.

Keywords: Sun-climate interaction, Regional surface air temperature and global warming, geomagnetic activity, solar activity cycle, Solar indices, Sunspot number.

1. Introduction

The role of solar activity on global climate has been examined by many authors with climate models (e.g., Meehl et al., 2009), as well as by comparing statistically solar and global, or regional, climate records e.g. (Lean and Rind, 2008; Benestad and Schmidt, 2009). The direct radiative forcing, due to increases in total solar irradiance since 1750, is estimated to be only +0.12 (–0.06, +0.18) W/m^2 (Forster et al., 2007). Nevertheless, a number of climate records reflected a significant response to variations in solar activity e.g.,(Versteegh, 2005; Soon, 2005; Mangini et al., 2005; Scafetta and West, 2007), providing evidence for a solar forcing effect, in spite of the fact that the underlying physical processes are still not yet understood.(El-Borie et al, 2010) presented a correlative study of the possible contributions for the two solar and geomagnetic activities components (aa and Rz) that may be closely associated with the climate, throughout the last 128years (1880–2008).

Amplification of the solar signal via indirect mechanisms may cause potentially lagged climate response. Models predict lags of 0–20 years due to the thermal inertia of the climate system (Schwartz, 2007). Studies of (El-Borie and Al–Thoyaib, 2006; El-Borie et al., 2007) displayed that the global temperature should lag the geomagnetic activity, with a correlation that reaches a maximum when the temperature lags by 6 years. (Eichler et al., 2009) studied

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the effect of solar forcing on the temperature in Altai. They found strong correlation between reconstructed temperature and solar activity that suggests solar forcing as a main driver for temperature variations during the period (1250–1850). The precisely dated records allowed for the identification of a 10–30 year lag between solar forcing and temperature response, underlining the importance of indirect Sun–climate mechanisms involving ocean–induced changes in atmospheric circulation. Solar contribution to temperature change became less important during industrial period 1850–2000 in the Altai region.

Several studies have been published reporting correlations between solar/geomagnetic activities and various climatic parameters. But the results were quite contradictory, even when highly statistically significant; both positive and negative correlations have been found between solar activity and climatic parameters (El-Borie et al., 2010). Over a solar cycle, Sun's activity has a dramatic effect on Earth's surface and atmosphere such as the variation in Earth's climate, which may be caused by varying UV and total radiation from the Sun (Haigh, 2007; Souza et al., 2009). (Georgieva and Kirov, 2006) found that the correlation between solar activity and surface air temperature in the 11 years sunspot cycle was positive during the 18th and 20th centuries and negative during the 19th century, and seemed to change systematically in consecutive secular solar cycles (Gleissberg) solar cycles. (Kilcik et al., 2009) considered the temperatures at different mid latitude zones and flare index data for the period from January 1975 to the end of December 2005, which covers almost three solar cycles, (21st- 23rd). They found significant correlations between solar activity and surface air temperature over the 50º–60º and 60º –70º zones for cycle 22 and over the 30º – 40º, 40º –50º, and 50º –60º zones for cycle 23, but have not any significant correlation for the cycle 21.

The present study offers the possibility to quantitatively evaluate the relationship between solar/geomagnetic activities and surface air temperature over a well–defined geographic area throughout the period 1881-2009.

2. Data and analysis

Figure 1: Egypt Climate Stations

18 climate stations have been selected in Egypt, which cover different areas in the country and selected upon several criteria, namely: different heights and locations (Figure 1), as well as long time span to cover the pre– and post–industrial era. We have considered Egypt surface air temperature (ESAT) for the period from January 1881 to December 2009, which covers 12 solar cycles ($12^{th} - 23^{rd}$). We used monthly sunspot number $\mathbf{Rz}$, solar flare, solar flux and total solar irradiance TSI as solar activity indicators as well as the geomagnetic index aa. Table 1 shows these indices and their time periods. We considered temperature as a climate indicator as it is "the most commonly and presumably the most accurately measured parameter" (Hoyt and Schatten, 1997).

Table 1: Geomagnetic and solar indices durations

Solar index	Period
$\mathbf{R_z}$	1881 – 2008
Solar Flares	1966 – 2008
Solar Flux	1948 – 2009
Total solar Irradiance	1979 – 2003
aa	1881 – 2008

Mean monthly temperature measurements were obtained from National Climate Data Center, NCDC,(http://www7.ncdc.noaa.gov/CDO/dataproduct).To obtain the continuity within the data of some stations presenting a lack of observation during a few months only, the cubic Spline interpolation method was applied. Data for geomagnetic activity, aa, was provided by the National Geophysical Data Center, NGDC,(http://www.ngdc.noaa.gov/stp/ GEOMAG/ aastar.shtml). The aa index is a measure of disturbances level of Earth's magnetic field based on magnetometer observations at two, nearly antipodal, stations in Australia and England.

Data for sunspot number $\mathbf{R_z}$ records used in this workwere obtained from the world data center WDC in Russia and Ukraine for Solar–Terrestrial Physics

(WDC–STP; http://www.wdcb.rssi.ru/stp/data/solar.act/sunspot/MONTHLY)

Data for solar flares are available at NOAA's National Geophysical Data Center, NGDC,

(ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FLARES/FLARES_INDEX/MONTHLY.PLT). They are classified as one of the most important solar events affecting the Earth (Klicik et al., 2008). Solar radio flux has no direct impact on climate, but it is widely used in Global Circulation Models, GCM, as a proxy for solar activity and is measured daily since 1947. The monthly solar flux records used in this work were obtained from the National Geophysical Data Center, NGDC,

(ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_RADIO/FLUX/Penticton_Observed/ monthly/MONTHLY.OBS). The total solar irradiance (TSI), which represents the total radiated power measured at 1 AU, above the atmosphere. This quantity summarizes the total radiative energy input to the Earth; TSI were obtained from (NGDC) (http://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_IRRADIANCE/compositeat).

To remove monthly and seasonal changes running average smoothing technique was applied to all data used in this study. Each of the solar activity indices and their corresponding temperature were segmented according to the length of solar cycles. To study the association between the solar activity and surface air temperature of Egypt, cross correlation method was applied for these segmentations and for the entire monthly data set. Spectral analysis is applied to obtain the cyclic behavior of each data set after smoothed using Hanning window.

3. Results and Discussion

Figure 2, shows the pattern of a 12-month running averages smoothing of ESAT for the period 1881–2009. Temperature shows a highly significant positive trend of 0.1^0C/yr from the late 19^{th} till the early 20^{th} centuries. From the beginning of the 20^{th} century till early 21th century, it was shown that a series of warming and cooling sub-periods are traced as follows: The period 1912–1943 illustrates a significant warming trend of 0.012^0C/yr, followed by a similar trend with a high significant cooling event along the period 1944–1975 to reach its minimum temperature of 21.94 ^{0}C in August 1975. Finally, a high significant warming period at the rate of 0.048^0C/yr appeared in the last four decades to reach its maximum temperature of 24.85^0C in August 2008. No trend is observed for the period from 1912 till 2009.

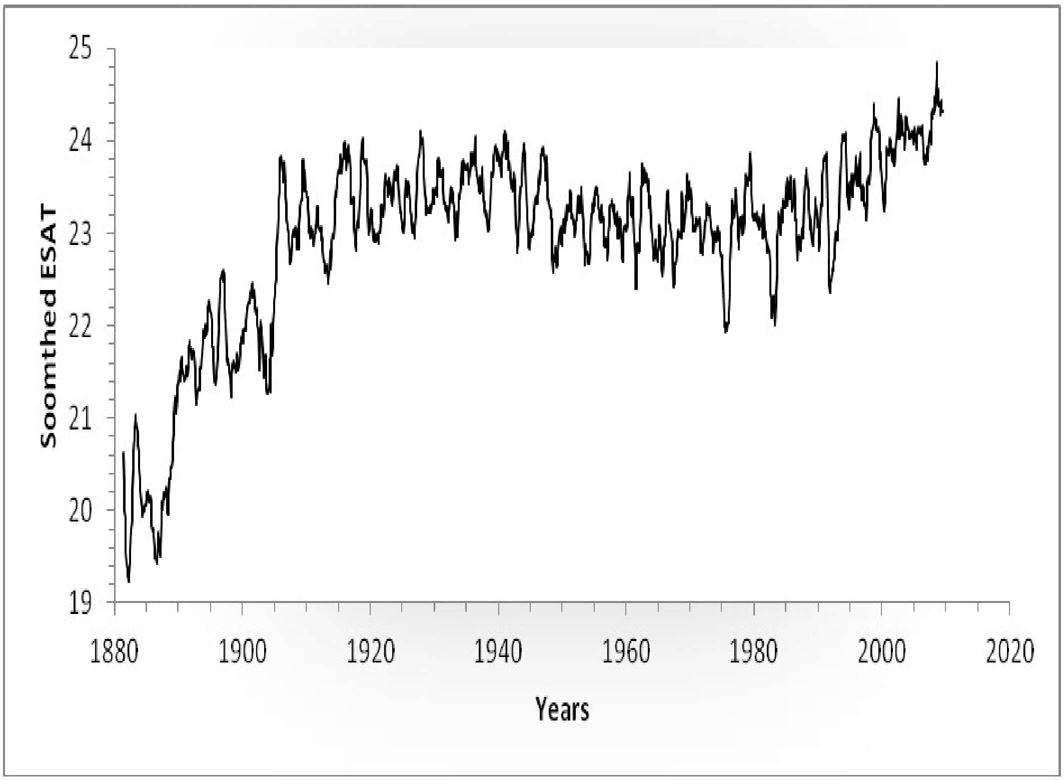


Figure 2: Time Series of 12 month running averages of ESAT for the period (1881-2009)

Figure 3 shows the cross correlation analysis between each of the solar-geomagnetic activity indices and ESAT for the entire data sets. The long term variation of solar geomagnetic indices have been found to be negatively correlated with the long term variation of ESAT during the interval from 1881–2009 at lag ~ (–6yrs). Uniquely, the total solar irradiance shows a positive correlation of 0.4 at lag ~ (–4yr) with ESAT with a periodicity of 11 year. In addition, correlation analyses between monthly solar activity indices and temperature data were applied at each cycle separately. Table 2 illustrates significant values for cross correlation coefficients obtained between each of the solar indices and ESAT for each solar cycle. It's noted the magnitude of correlation and the location in months between brackets.

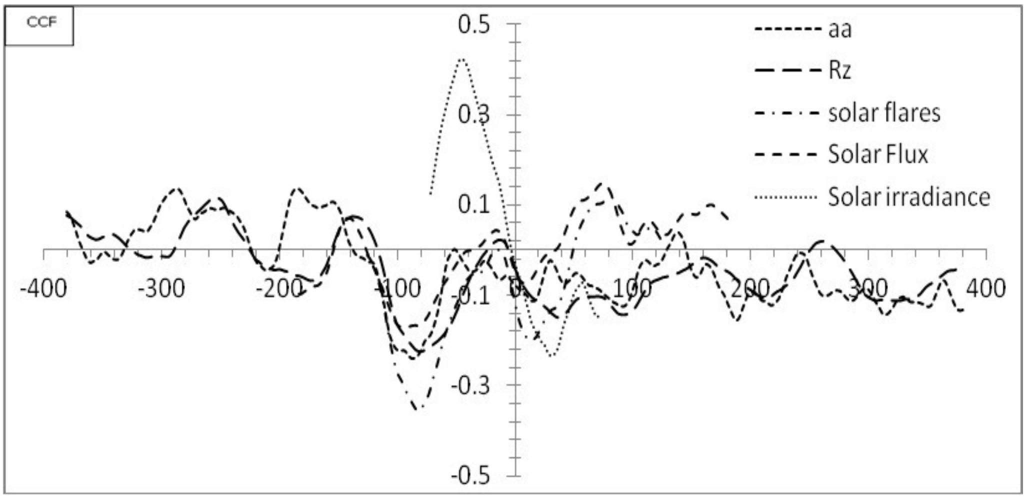


Figure 3: Cross correlation between each of the Solar-geomagnetic indices and ESAT for the entire monthly data.

Table 2 shows the lag correlations between each solar-geomagnetic index and ESAT after segmentation takes place according to each solar cycle length. In cycle 12, Figure (4a), one can see that Rz leads aa by about 3yr on its effect on ESAT to reach maximum negative correlation of ~(-0.6) between Rz and ESAT. Positive correlation of (~0.56) in the same phase are observed for both aa and Rz with ESAT on cycles 13 and 14 at lag – (1.5-2yr) for cycle 13 and at 1yr for cycle 14, Figures (4b,4c). Rz lead aa in its effect on ESAT by 6m to reach correlation coefficient of -0.55 on cycle 15, Figure (4d). In cycle16, Figure (4e) shows that aa lead Rz by 1yr on its effect on ESAT with positive correlation of 0.38. In cycle 17, Figure (4f) both correlation between aa and Rz with ESAT behave as out of phase with each other. On cycle 18, Figure (4g), aa and Rz have the same phase but lead solar flux by ~1yr on their effect on ESAT. High negative correlation coefficient of –0.65 at lag 2yr is found between aa and ESAT in this cycle. It is obvious that aa experiences a cyclic behavior of a period ~3years with ESAT on cycle 19, Figure (4h). It is also observed that Rz and solar flux have the same pattern of correlation in this cycle. In cycles 20, Figure (4i) show that all solar activity indices behave similar with approximately positive correlation coefficient of 0.53 with ESAT but are out of phase with the geomagnetic activity aa. It is observed on cycle 21, Figure (4j) that all the solar indices have the same phase with negative correlation coefficients of ~(-0.58) at the same lag of 2yr. It is also observed that these indices are lead aa by about 21m on this cycle. This result contradicts with that obtained by (Kilcik et al., 2009), which revealed that there is no significant correlation observed between temperature at different mid-latitude zones and flare index data for the cycle 21. In cycle 22, Figure (4k), aa shows a cyclic behavior of period ~3years with ESAT, a negative correlation of ~(–0.4) with the same phase are observed for Rz, Solar Flares, Solar Flux and total solar irradiance at lag 8m. In cycle 23, Figure (4l) the total solar irradiance shows positive correlation of 0.5 at lag 3m, geomagnetic activity index aa shows a negative correlation –0.56 at lag –39m.

We have related the change in the correlation between solar activity cycle and ESAT to the change in the north–south sunspot area. Total sunspot area in the northern and southern solar hemisphere S_N and S_S, respectively, have been calculated for each solar cycle. We found that when southern solar hemisphere is more active results in a higher temperature in sunspot minimum and lower in sunspot maximum, and when the northern solar hemisphere is more active, the temperature becomes higher in sunspot maximum and lower in sunspot minimum. This result confirms in all cycles except solar cycle 13.

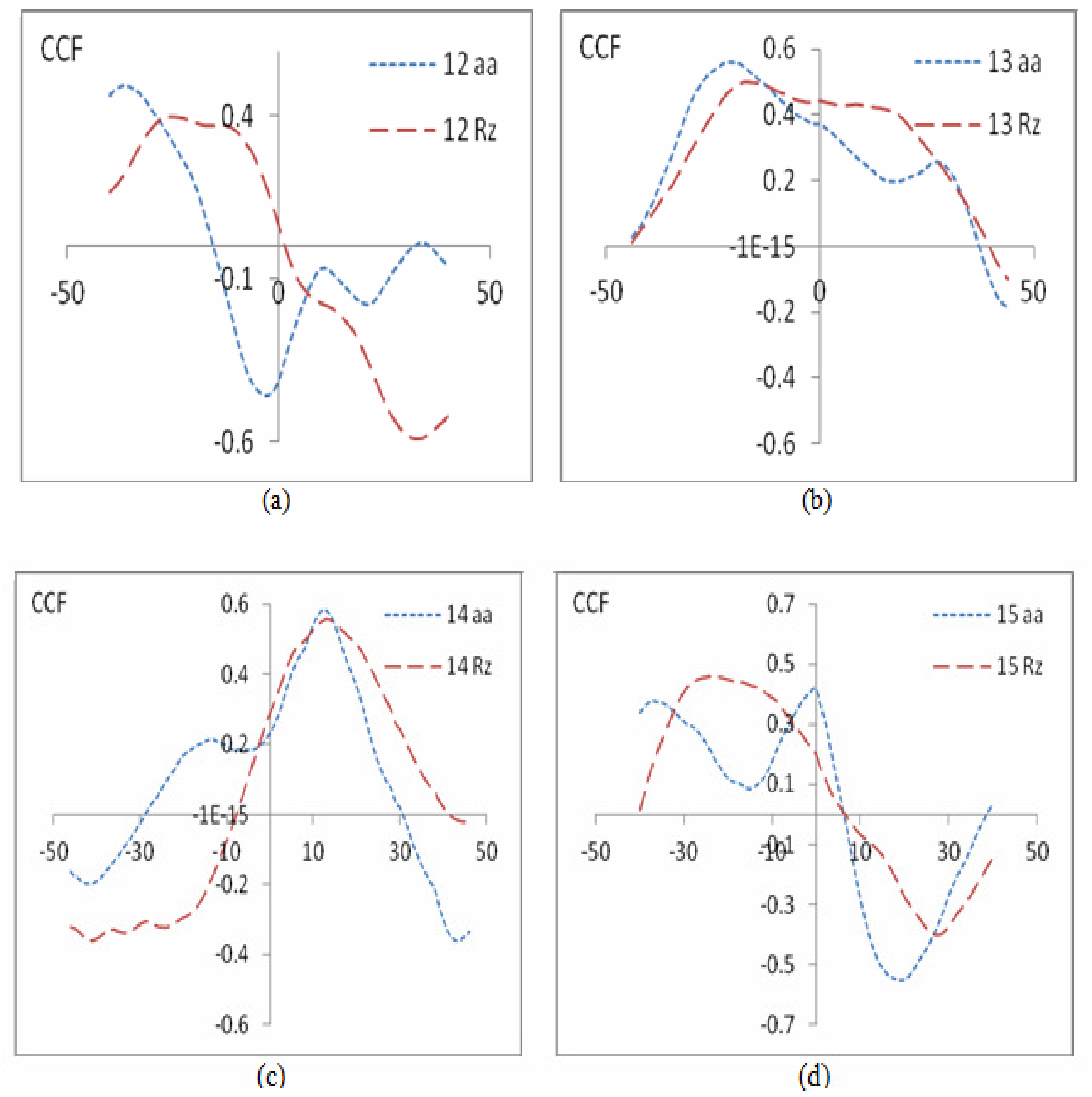
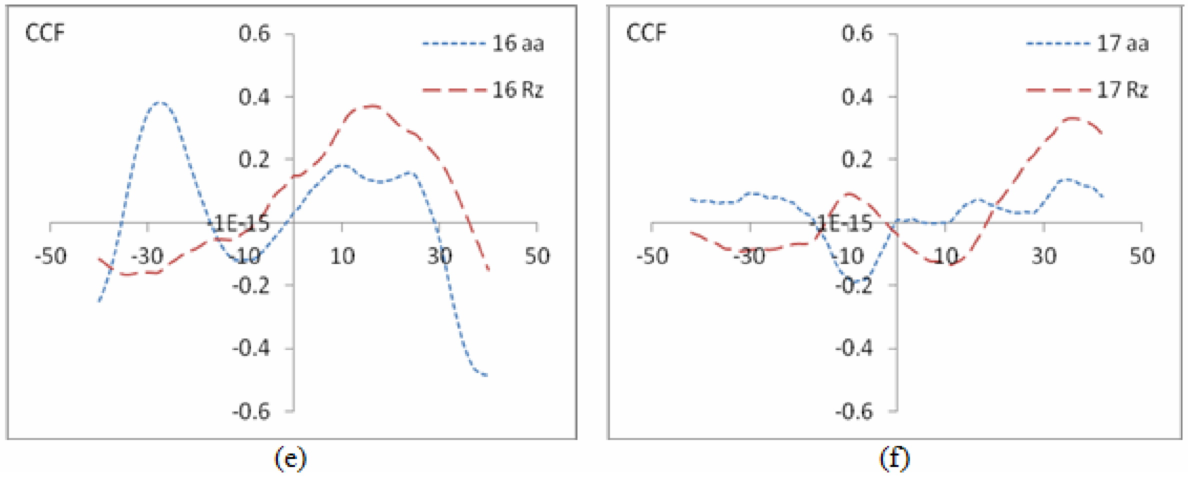
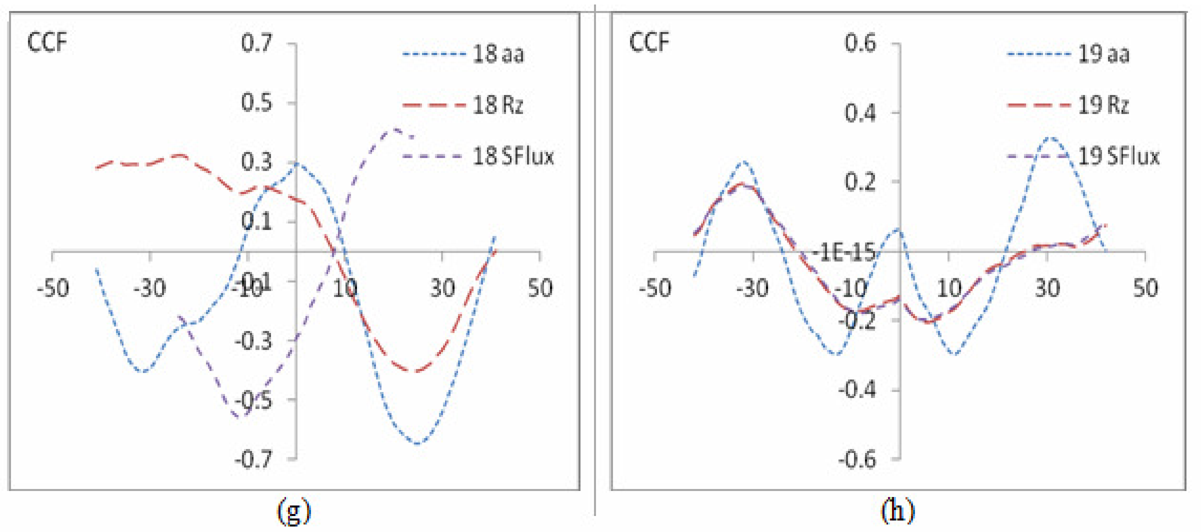


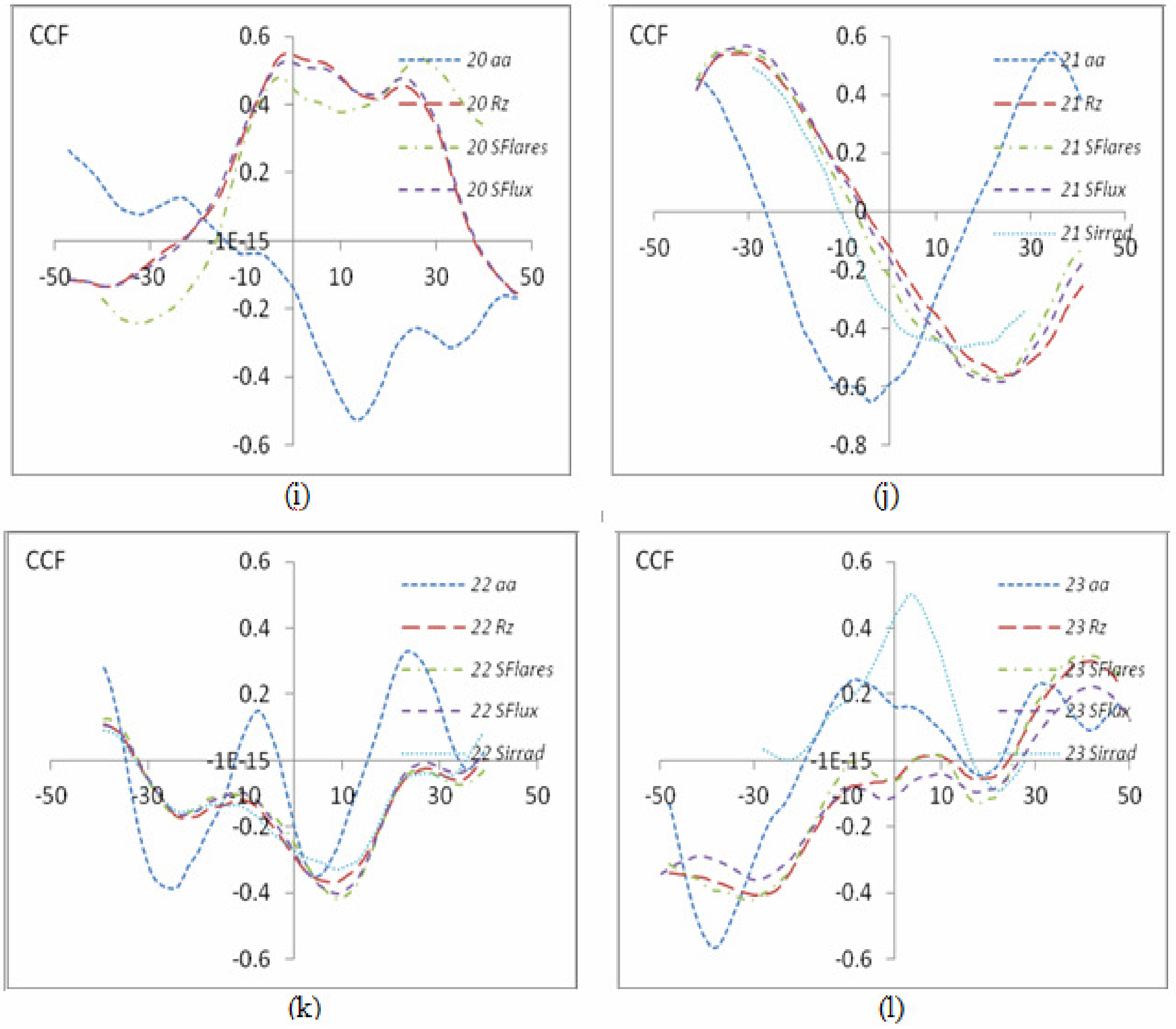
Figure 4: Lag correlations between solar-geomagnetic indices and ESAT for solar cycles 12-23





(g) (h)

Figure 4 (continued): Lag correlations between solar-geomagnetic indices and ESAT for solar cycles 12-23



(i) (j)
(k) (l)

Figure 4 (continued): Lag correlations between and solar-geomagnetic indices and ESAT for solar cycles 12-23

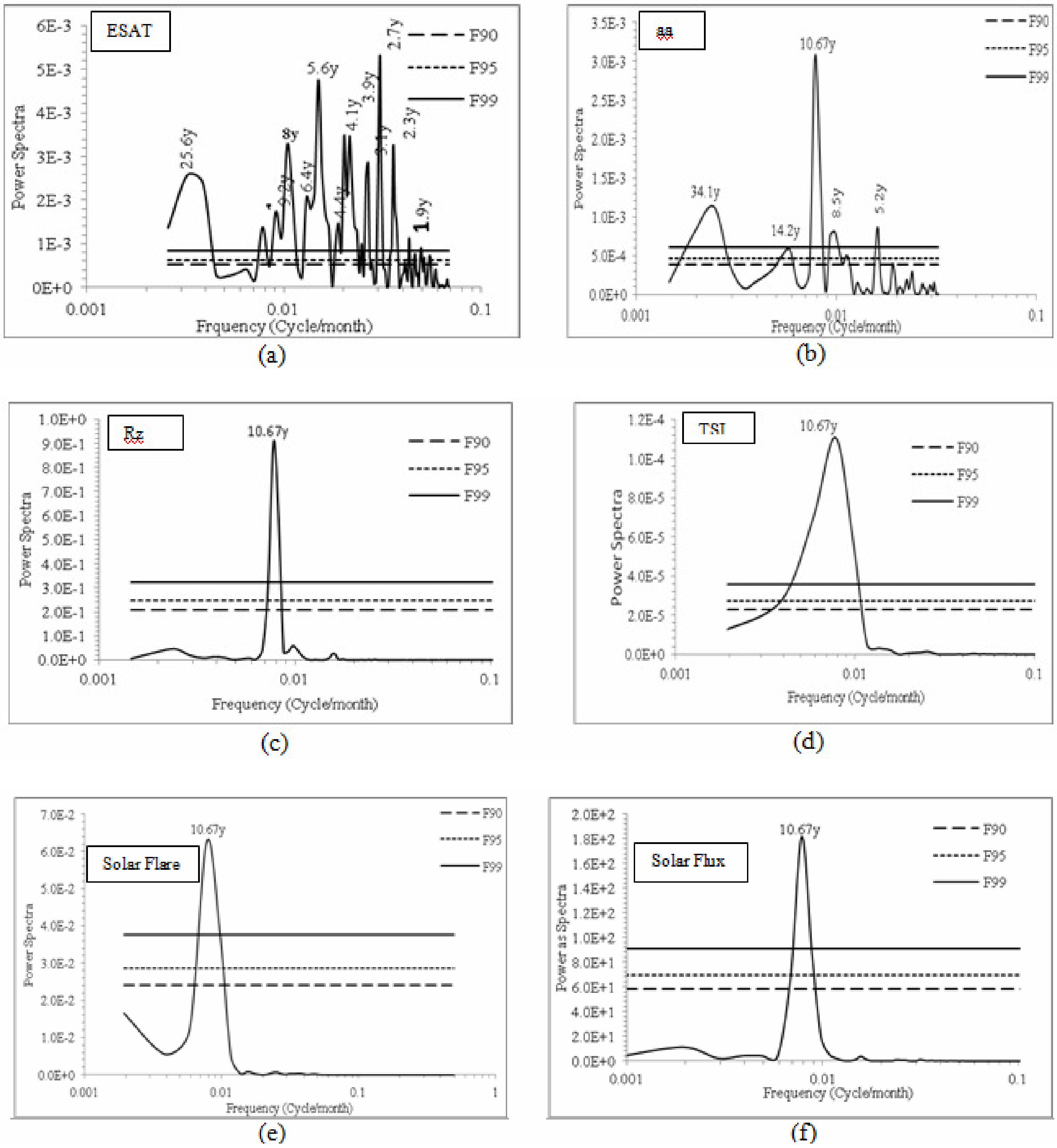
Table 2: Correlation coefficients between Solar indices and ESAT for Solar cycles (12–23)

Solar Cycles	aa	Rz	Solar Flares	Solar Flux	Solar Irradiance
12	(–0.45,-5m)	(–0.59,32m)			
13	(0.56,-22m)	(0.5,-18m)			
14	(0.57,11m)	(0.52,11m)			
15	(–0.55,19m)	(0.46,-25m)			
16	(0.38,-28m)	(0.37,16m)			
17	(–0.18,-10m)	(0.32,34m)			
18	(–0.65,24m)	(-0.4,25m)		(–0.55,-11m)	
19	(0.32,30m)	(0.2,-33m)		(0.18,-33m)	
20	(–0.5,12m)	(0.54,-3m)	(0.53,25m)	(0.52,-1m)	
21	(–0.65,-3m)	(–0.56,24m)	(–0.57,24m)	(–0.58,24m)	(–0.45,24m)
22	(–0.4,-26m)	(–0.37,8m)	(–0.42,9m)	(–0.4, 8m)	(–0.32,8m)
23	(–0.56,-39m)	(–0.4, -29m)	(–0.42,-31m)	(–0.36, -31m)	(0.5,3m)

Figure 5 shows power spectrum of ESAT and each of the solar–geomagnetic activity indices for the whole available data series with confidence limits of 90%, 95%, and 99%. The prominent periods of 5.6 and 2.7 yrs have been detected in ESAT spectra, Figure (5a). Further significant periods of 25.6yr, 8yr, and 3–4yrs have been detected besides them, a peak of 10.7yr is also observed with small amplitude. The significance of 5.6 yr periodicity is about 90% confidence level. This period may be related to geomagnetic activity (5.25–year) and indirectly to solar activity. It is obvious that the peak 25.9yr appeared more significant with larger amplitude than 10.7~11year cycle. This result is consistent with results obtained by (Eichler et al., 2009), who studied the global surface temperature dependence on solar activity over different time scales and they concluded that higher correlation of global temperature anomaly with sunspot number occurs around a 22 years solar cycle band. The 11 years signal in this anomaly is highly non–steady (El-Borie et al., 2011a). The most significant peak 2.7yrs that appears in this spectrum is closely associated to quasi–biennial oscillations (El-Borie et al., 2011b). Also an 8yr peak is observed it is may be related to Northern Atlantic Oscillation (NAO) (El Mallah and El Sharkawy, 2011). 11yr cycle appears highly significant in each of the solar-geomagnetic activity indices, as shown in Figure (5b-5f).

4. Conclusion

We have studied the dependence of Egypt surface air temperature (ESAT) on solar/geomagnetic activities over different time scales. ESAT shows series of warming and cooling ending with a high significant warming trend of 1.392^{0}C along the last four decades. No trend is observed for the whole period from 1912 to 2009. Negative correlation for the entire period between ESAT and solar- geomagnetic activity indices are observed at lag time ~(–6yrs), except total solar irradiance that reveals positive correlation (0.4%) with ESAT. After the segmentation that applied to the data sets according to the solar cycle lengths, we found that the sign of the correlation between ESAT and Rz depends on North–South sunspot area, being positive when the Northern solar hemisphere is predominantly more active, and negative when more active is the southern hemisphere except for the cycle 13. Our spectral analysis of ESAT reveals significant periods of 25.6yr, 10.7yr, 8yr, and 2–5yr, confirming a remarkable role of solar and geomagnetic activities on Egypt's temperatures. We conclude that signature of solar activity effect exists on surface air temperature of Egypt.



(a) (b) (c) (d) (e) (f)

Figure 5: Power spectra of ESAT and each of the solar-geomagnetic indices.

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