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Research Article

Solar and Geomagnetic Activity Effects on Climate at Regional and Global Scales: Case Study- USA, Japan, and China

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Abstract: In this study we investigate the effects of solar and geomagnetic parameters on the mean surface air temperatures (MSAT) recorded at countries which covers a wide range of geographic latitudes from 20º N to 71º N. In this case, we select three countries located in the northern hemisphere which are; USA, Japan, and China for the period 1880-2004. From Correlation analyses we found that Total Solar Irradiance (TSI) has the greatest effect on the climate change and independent on the temperature group classification, a small change in energy flux that reached the Earth may play an important or a leading role in climate changes in such countries. In addition the earlier changes of solar parameters may partially affect the present changes in temperatures. The excess of solar energy stored and accumulated for few future months (or even years) in the near-Earth system, lead to the temperature variability. Power spectral density (PSD) of the monthly values for solar and geomagnetic indices and the mean surface air temperature (MSAT) of USA, Japan, and China at different altitudes G1, G2, G3, G4, G5 have been performed. PSD show that the 22 yr solar magnetic cycle (Hale cycle) is more effect on MSAT than solar activity cycle. Generally, our results display that the solar variability parameters play an important role in climate changes and cannot be excluded from the responsibility of continuous global or regional warming.

Keyword: Geomagnetic activity- sunspot number- regional temperature- climate change- cross correlation- spectral analysis.

INTRODUCTION

While it is obvious that the Sun is tremendously important for the life on the Earth, the way that the solar output variations interact with the atmosphere is still not well understood. We know that the energy, produced by fusion reactions in the solar core, is transferred to the outer upper layers of the sun by radiation and convection processes to finally escape into space by radiation on all wavelengths of the electromagnetic spectrum. As the energy variations are far from the constancy, and due to the interaction between such radiations and the Earth magnetic field, we may expect changes on the terrestrial level-auroras, proton events, geomagnetic storms which may, in turn, have some disruptive effects on the Earth such as on communications, on board satellite equipment's, navigation systems, electric powers, pipelines, etc.. Solar changes are today easily traced through many activity indicators such as sunspot number, coronal mass ejection (CME), solar flare and prominences, etc. These indicators show cyclic behaviors from days to hundreds of years. One of the longest data set available is the sunspot number and sunspot area series, which exhibit long-term cyclic variations of 11 years (Schwabe cycle), 22 years (Hale cycle) and 80–90 years (Gleissberg cycle), and also some other periods such as those of 35 years[1, 2], or even longer of 210-year (Suess cycle)[3]. Short-term changes have also been recorded in solar Flare observations and irradiance measurements[4].

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[5]. 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[6, 7]. Georgieva and Kirov[8] 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). Kilcik *et al.*[4], investigated the effects of solar activity on the surface air temperature of Turkey and found a significant correlation between solar activity and surface air temperature for the solar cycle 23. Kilcik *et al.*[9], 2010, 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 part 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.

DATA: We investigate the effects of solar and geomagnetic parameters on the mean surface air temperatures (MSAT) recorded at countries which covers a wide range of geographic latitudes from 20º N to 71º N. In this study, we have selected three countries via northern hemisphere which are; USA, Japan, and China. This enables us to understand existence of solar activity effects on the regional and global temperatures. We used surface air temperature as climate parameter and geomagnetic activity index (aa), sunspot number (Rz), solar radio flux (F10.7), solar flare index (FI), and total solar irradiance (TSI) data as solar activity and geomagnetic indicators. We considered the parameters temperature and solar activity indicators data from the beginning of January 1880 to the end of December 2004, which cover almost 12 solar cycles (12^{th} - 23^{rd}).

To investigate Sun-climate relationship on local/global scales, we used only monthly surface air temperature data of USA, Japan, and China since the ‘‘temperature is the most commonly, and presumably the most accurately, measured parameter’’

There are few missed values in our raw data and the methodologies studies so far assume complete data, so we are forced to fit models and make statistical inference based on partially observed time series. The cubic Spline interpolation method was applied to obtain the continuity within the data.

To remove monthly and seasonal changes, all griddled monthly data were smoothed with 12-month running average.

The raw temperature data used in this study cover 64 city centers whose chosen for which continuous records data were available. It is well known that the surface air temperature shows serious variations with the altitude and the air pressure. To avoid the possible disharmony and to keep the homogeneity among the city data, we separated them into ~30-mbar pressure grids in which the minimum pressure value was set to 825 mbar (Group 5) and the maximum value at 1013 mbar (Group 1). **Table1.1** shows station number in each group, their elevation in meter, and atmospheric pressure in mbar.

Table-1.1: MSAT temperature groups

Temperature groups	Number of stations	Elevation (m)	Pressure (mbar)
G1	39	1-250	1013-984
G2	17	250-500	984-955
G3	1	500-750	955-927
G4	4	750-1000	927-899
G5	3	1400-1700	856-825
Total	64	0-1700	1013-825

Altitudes of our data station vary between 1 and 1700m. Thus, we obtained five sub-regions in which there are minimum one station in Group 3 and maximum 39 stations in Group 1.

RESULTS AND DISCUSSION

Running Cross Correlation: Results of the running-cross correlation analysis (based on monthly averages) are shown in Figures 1.1 to 1.6. The lag time (τ) has been considered. For these correlations, τ is chosen such that it takes a maximum of 25 % data length. The $\tau = 0$ means that both data sets are in time (zero lag).

Figure 1.1 shows the cross correlation analysis between each of the solar geomagnetic activity indices and average temperature data all climate stations under study (1880-2004). From **Fig. 1.1,** the total solar irradiance (TSI-MSAT) shows a clear cycle of ≈ 11 years with highly correlation coefficient of 0.6 at lag 2 yr. FI-MSAT and F10.7-MSAT correlations are in anti-phase at negative lag of ~4yrs with correlation coefficients of 0.2, showing a cyclicity of 9.3yr. The sunspot number Rz and geomagnetic index aa have no significant effects of the MSAT.

Correlation analyses between monthly solar activity indices and temperature data are applied to each group (G1to G5), separately. **Figure 1.2** (plots a-e) show the correlation of aa-G1 to aa-G5. Both aa-G1 and aa-G4 (plot 1.2a, d) show moderate correlation of magnitude (~ 0.15) at lag ~2yrs. aa-G2 (plot

1.2b), reflects no periodicity with correlation of (~ -0.25) when aa leads G2 by 5 yr. On the other hand, aa-G3 has a correlation coefficient (~ 0.2) at 70 months. Finally, the aa-G5 displayed a broad correlation ranging from 40-80 months.

Figure 1.3 (plots a-e) illustrate running cross correlations between sunspot number (Rz) and each group throughout ± 150 months lag time. Plots (1.3b and 1.3c) show the role of the sunspot number on both temperature groups G2 and G3, indicating the 11-yr solar activity effects on record temperatures. No cyclicity with no significant correlation appear in the relation between (Rz-G1), (Rz-G4), and (Rz-G5) as shown in plots (1.3a, d,e).

Solar flare (Figure 1.4) shows cyclicity for about 11yrs with all groups with moderate correlation coefficients of (0.3-0.5) at different lags.

The cross correlation between solar flux (F10.7) and all groups (Figure 1.5) show that maximum correlation coefficients is obtained between solar flux and G2 to reach 0.3 at a lag zero and with G3 to reach 0.29 at a lag 87 month. An 11 year cycle appear for all groups.

Finally, Fig 1.6a to 1.6e, display the TSI-G1 to TSI-G5 running correlations at ± 150 months lag time. TSI is well correlated with G2 for correlation coefficient of r = -0.57 at a lag 48 month, it also has a correlation coefficient r= 0.5 at a lag 48 month with G1. A clear 11-yr cycle of solar effect appears almost in all groups.

Table 1.2 illustrates significant values for running cross correlation coefficients (r) obtained between each of the solar indices and temperature data for each group. One can see that the most effective solar parameters on the surface temperature at different altitudes of all groups are TSI and solar flares.

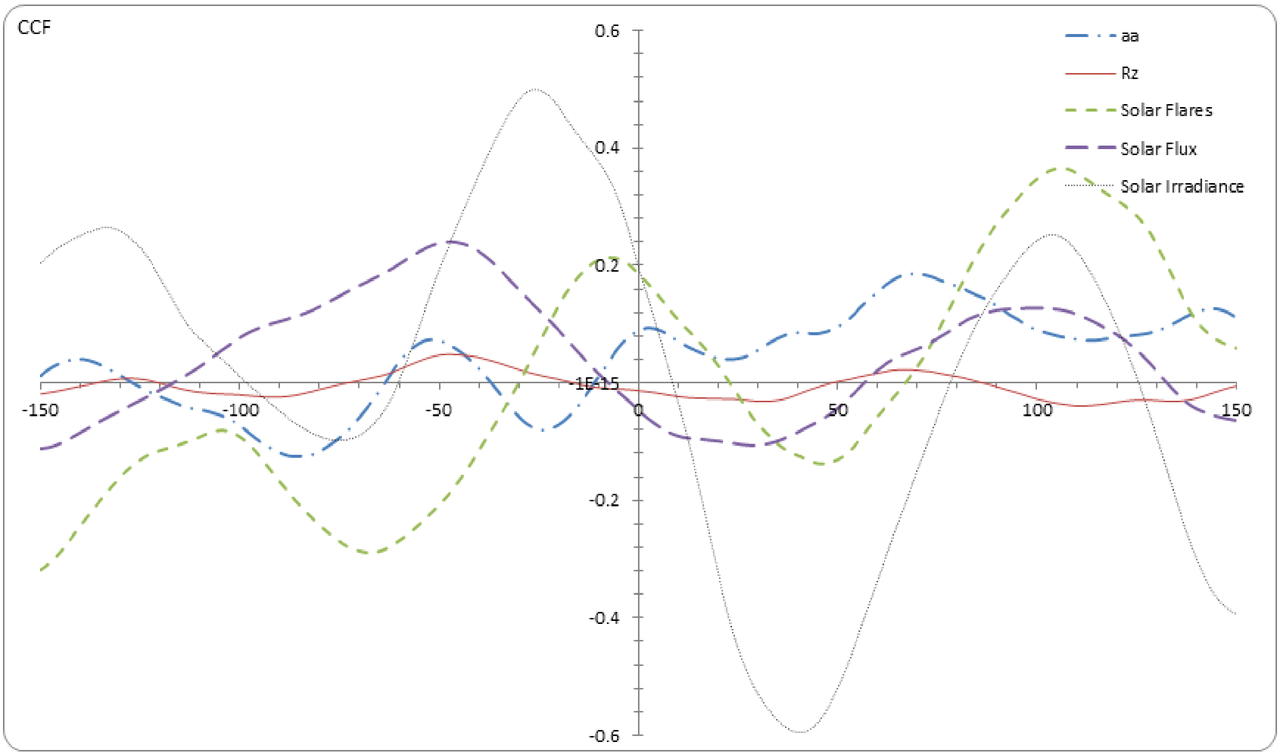

Figure 1.1: Running cross correlations between each of the solar/geomagnetic indices and Temperature data for the entire data set (1880-2004).

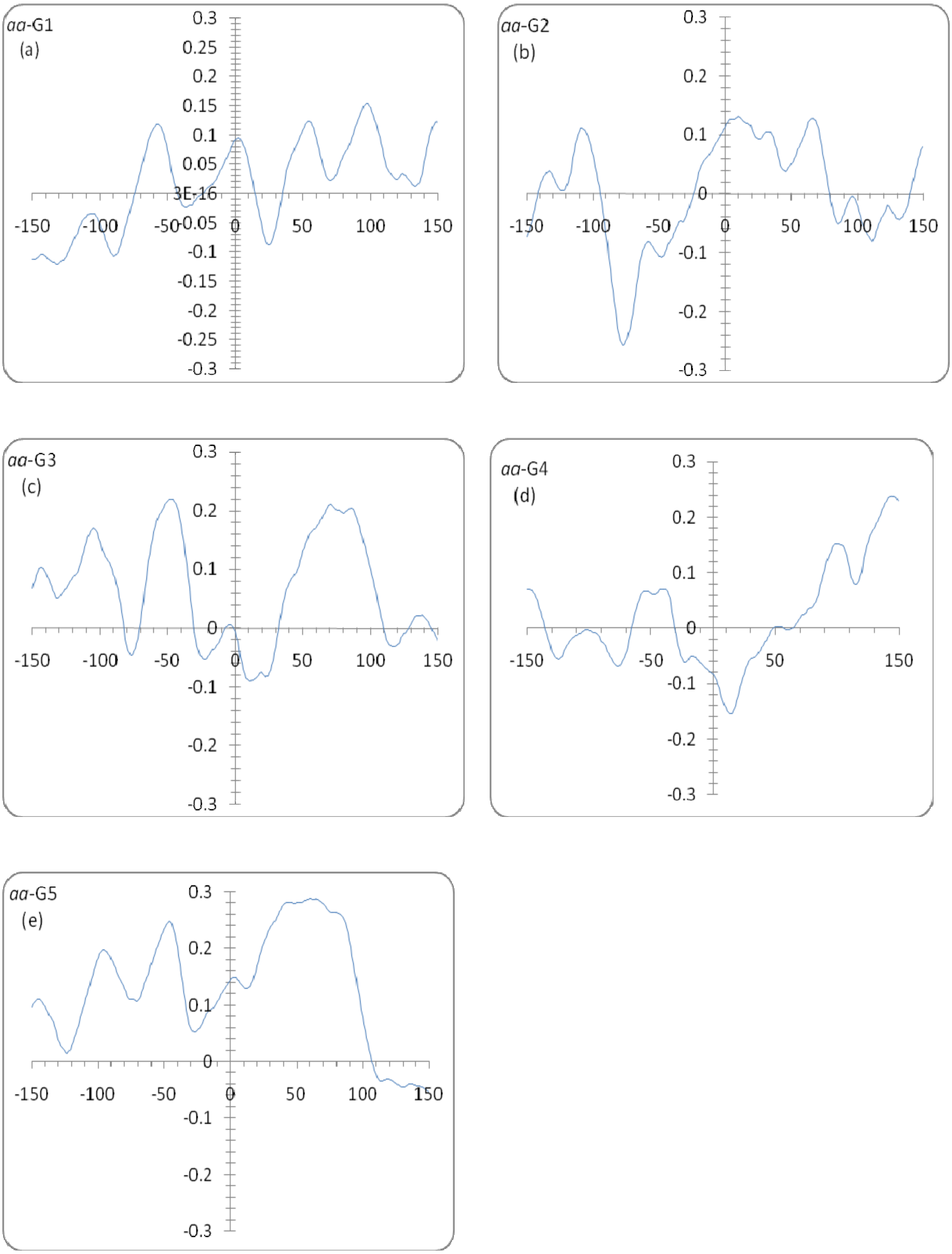

Figure 1.2: Running cross correlation between each temperature group and geomagnetic activity index aa

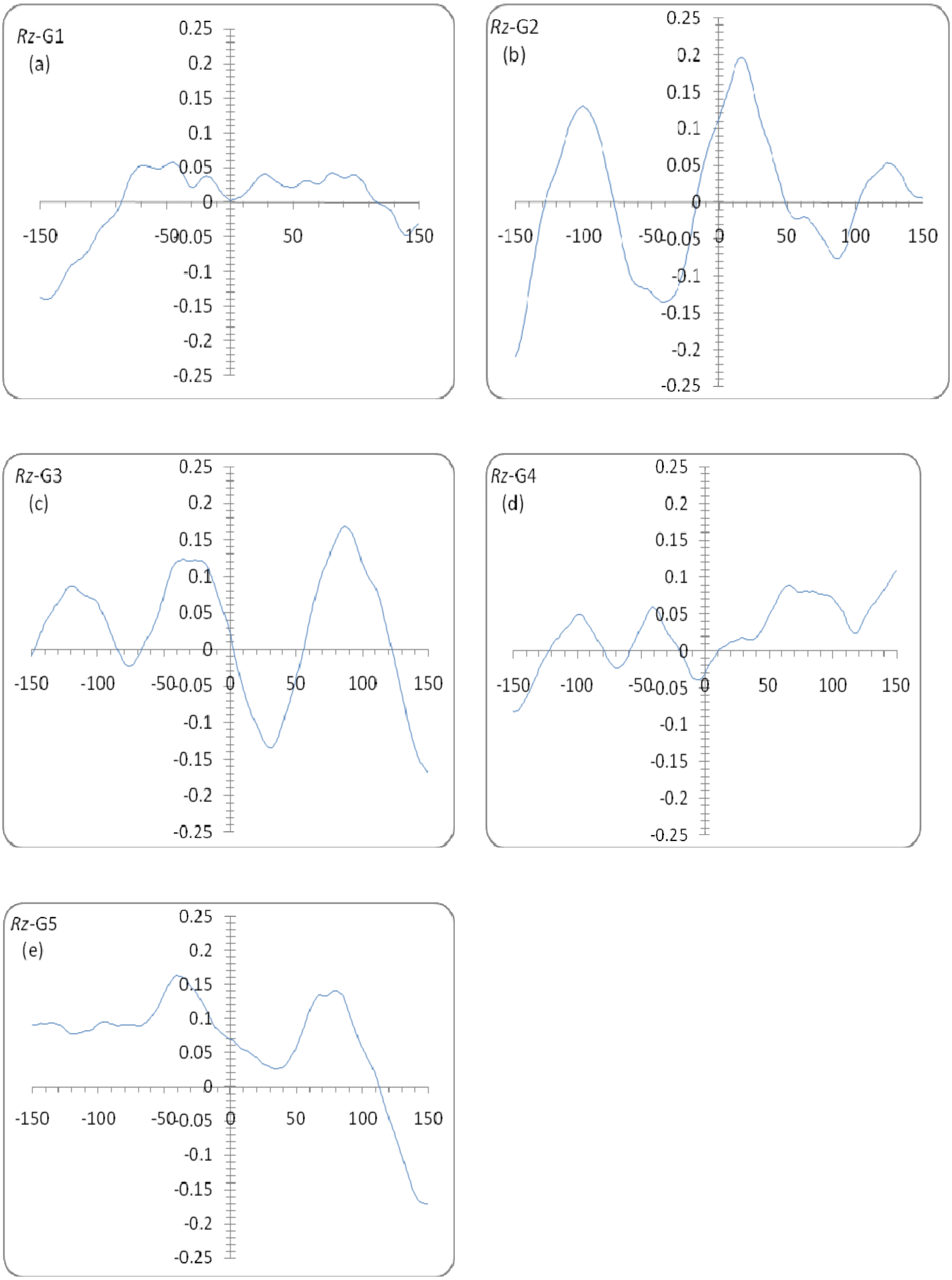

Figure 1.3: Running cross correlation between each temperature group and sunspot number Rz.

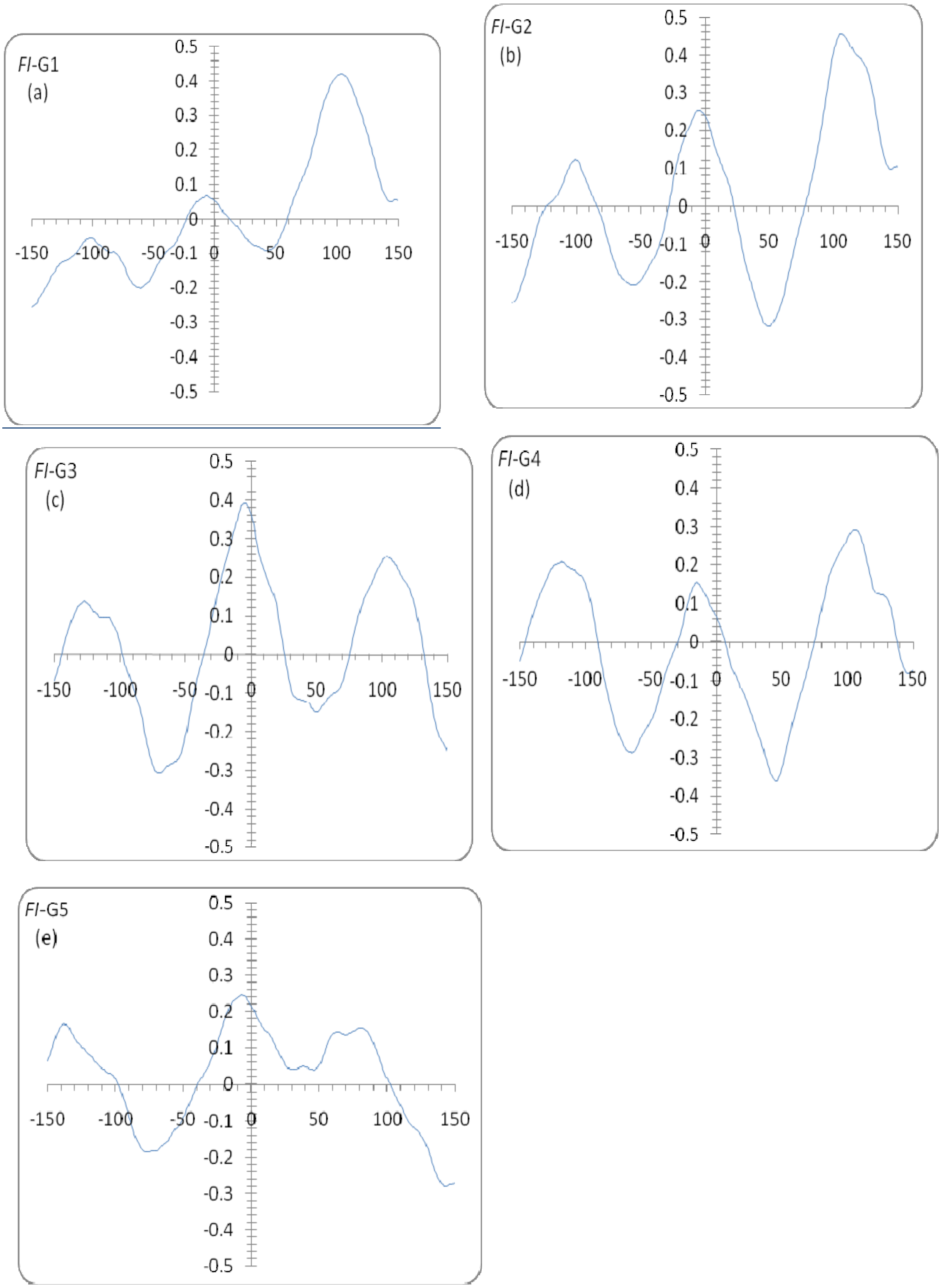

Figure 1.4: Running cross correlation between each temperature group and solar flares.

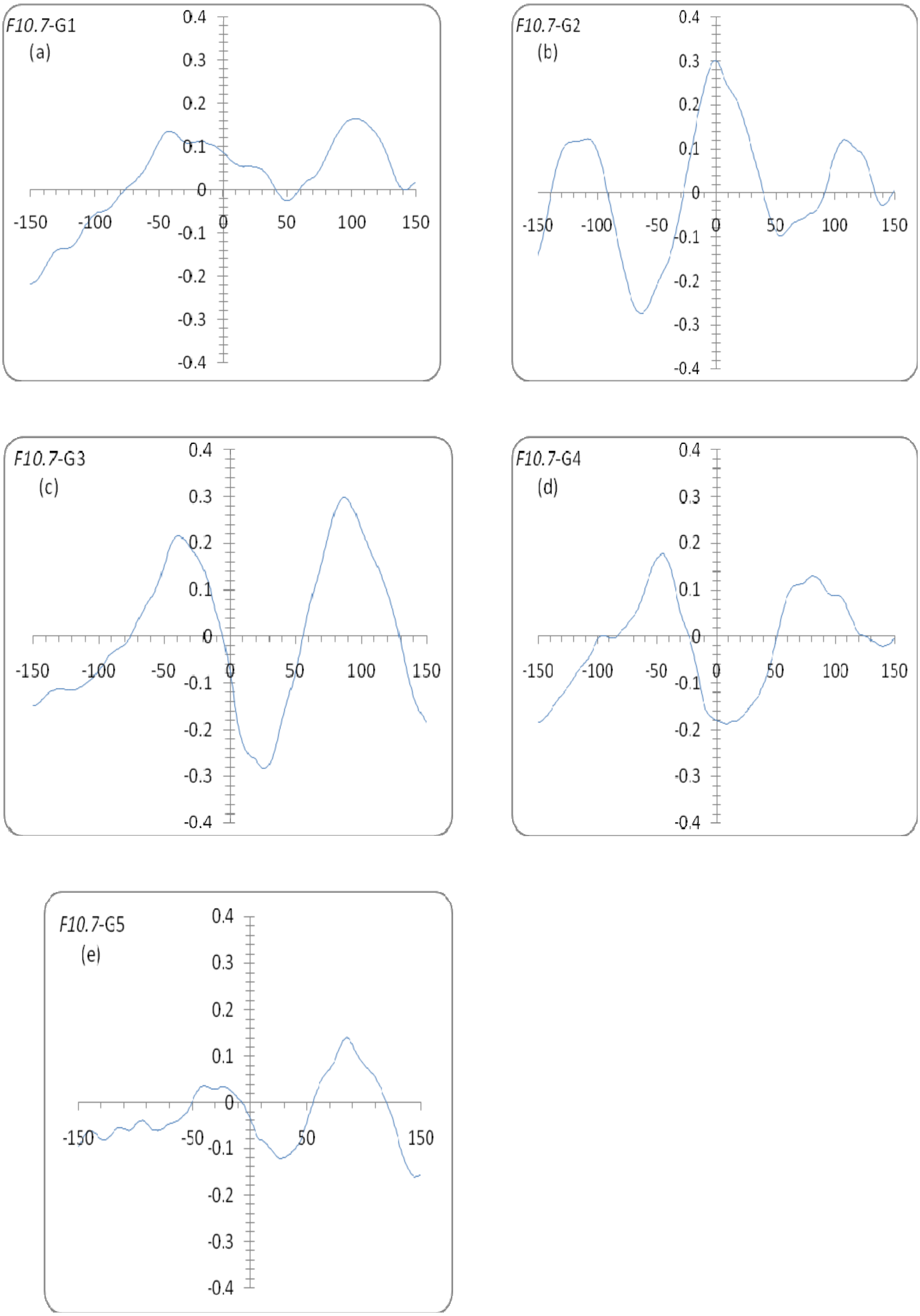

Figure 1.5: Running cross correlation between each temperature group and solar radio flux.

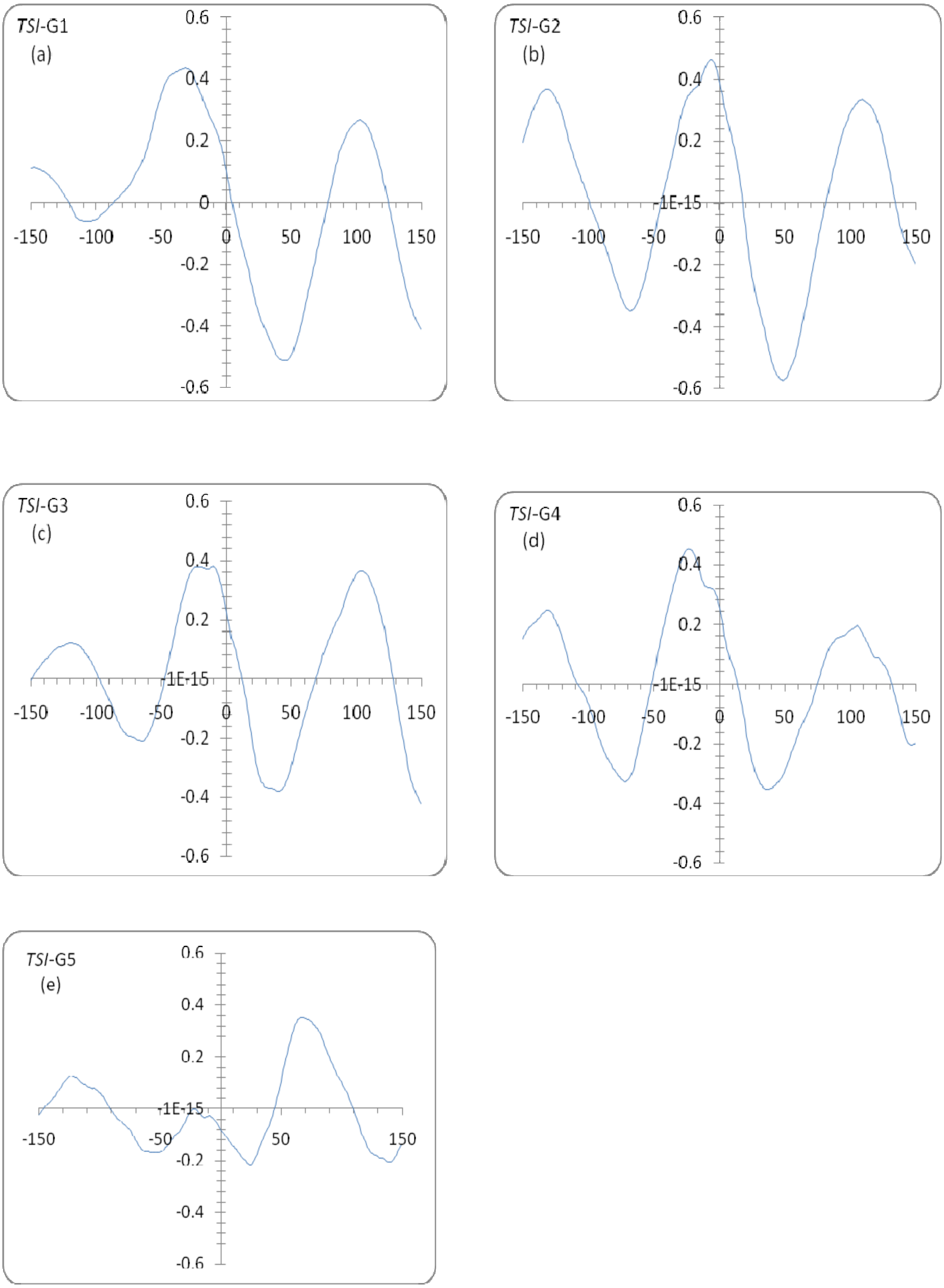

Figure 1.6: Running cross correlation between each temperature group and total solar irradiance.

Table-1.2: Magnitudes of correlations between solar/geomagnetic indices and Temperature data for each temperature group

Temperature groups	(lag in months, correlation magnitude r)				
	aa	Rz	FI	F10.7	TSI
G1	(+97, +0.16)	(–146, +0.14)	(–150, –0.25) (+104, +0.42)	(–150, –0.22) (+104, +0.17)	(–32, +0.44) (+45, +0.51) (+102, +0.27)
G2	(–77, –0.26)	(–150, –0.21) (+16, +0.20)	(–150, –0.26) (–5, +0.25) (+50, –0.32) (+106, +0.46)	(–63,–0.27) (0, +0.30)	(–132, +0.37) (–68, –0.35) (–7, +0.46) (+48,–0.57)
G3	(–47, +0.22) (+70, +0.21)	(+87, +0.17) (+150, –0.17)	(–71, –0.31) (–5, +0.39) (+104, +0.26)	(–39, +0.22) (+26, –0.23) (+87, +0.30)	(–21, +0.38) (+40, –0.38) (+103, +0.36) (+150, –0.43)
G4	(+146, +0.24)	(+150, +0.11)	(–65, –0.29) (+46, –0.36) (+106, +0.29)	(–149, –0.19) (–45, +0.18) (+8, –0.19)	(–72, –0.33) (–24, +0.45) (+37, –0.35) (+105, +0.20)
G5	(–46, +0.25) (+60, +0.29)	(–41, +0.16) (+149, –0.17)	(–77, –0.19) (–7, +0.25) (+143, –0.28)	(+145, –0.16)	(+24, –0.22) (+67, +0.35) (+140, –0.21)

SPECTRAL ANAYLSIS

We analyzed long series of the solar/geomagnetic activities and surface temperature throughout 1880-2004, in order to ascertain whether some characteristics of the spectral peaks occurring at periods more than one yr. In order to look for periodicities, especially in the last few years, monthly averages of the data were computed.

Following the established analysis reported before[10], we have choice the 12-months running average. The choice of a 12-month interval for the running averages was made to emphasize variations with long duration, while suppressing fluctuations on time scales of one year or less. Significant gaps in measures were treated. Thus, the data set is smoothed with all the data gaps filled in.

Power spectral density (PSD) of the monthly values for geomagnetic index aa, sunspot number Rz, solar flares, solar flux, total solar irradiance (TSI) and the mean surface air temperature (MSAT) of USA, Japan, and China at different altitudes G1, G2, G3, G4, G5 have been calculated by using the fast Fourier transformation technique (FFT). The results were smoothed out using the Hanning window. The confidence levels 90%, 95%, 99% have been computed.

Figure 1.7 (plots a-d) displays the power spectral density for the MSAT for all groups (G1 to G5). The actual frequency range is from (2.2 x 10^{-3} to 0.5) m^{-1} (corresponding to from 2m to 38 yrs.). The indicated statistical uncertainties (dashes and solid horizontal lines) show the 90%, 95% and 99%

confidence levels). In plot 1.7a, there are remarkable spectral peaks for G1 that located at 21.3, 15.5, 11.4, 9.5, 7.8, 6.3, 5.7, 5.2, 4.4, 4.0, 3.4, 2.7, 2.4, and 1.9 years.

The variations of G1 show well correlation with the interplanetary magnetic field reversals every 22-year. Solar cycle dependence in PSD of G1is almost observed well.

The following plot (1.7b), for the spectra of G2, display significant peaks at 21.3, 12.2, 8.5, 6.6, 5.3, 4.5, 4.1, 3.4, 3.1, 2.5, and 1.9 years. Furthermore, the plot (1.7c) shows significant peaks of G3 at 21.2, 14.2, 9.5, and 4.27 yr. So, significant peaks in the three plots exists 21.2-21.3 yr and 4.3-4.5 yr, indicating the same origin effect.

Significant peaks in the two plots exist at wavelengths of 21, 14, 6.6 and 3.9 yrs for G4 and at 28.4, 4.1, 3.3and 2.5yr for G5. It has been noticed that the spectrum variations observed for G3 and G4 are more pronounced than that other, indicating to different formation mechanism causes. It is obvious from **Figure 1.7** that prominent period of ~22 year corresponding to Hale cycle have been detected on all groups except G5, with different amplitudes.

It is necessary to point out that absence of the role of solar activity every 11-year (expect for spectra of G1). This displays that the interplanetary magnetic field (IMF) effect is a solar forcing and more effect on MSAT than the solar activity cycle.

Other significant common peaks appear in all the spectra of MSAT are (3.3-4.3) years with its maximum amplitude on G5 and its minimum on G2, which is caused by the dual-peak structure of the geomagnetic activity or it is caused by sector boundary of crossings of the achieved regions in the solar, as previously reported[11].

Figure (1.8) shows the spectral analyses of solar indices, which display peaks of aa at 34.1, 14.2, 10.67, 8.5, 7.4, 5.2, and 4.3 year. Furthermore, significant peak at 10.67 year appear in all solar indices, which is the most established cycle of the solar activity.

A simple explanation for ~ 8.2 - 8.3 year peak in aa is that it may be related to the formation rate and the magnetic structure of achieving regions in the solar southern hemisphere. The period of 5.2 years in aa could be the 11-year solar cycle first harmonic, or it could be caused by a solar wind density periodicity.

Table (1.3) indicates the observed periodicities for the five temperature regions and the studied solar indices for the 1880–2004. The observed peak of 8.25 ± 0.4 year has been observed in the running averages (100-day measures) of geomagnetic index Ap10.

Because the plasma speed and the magnetic field affect geomagnetic activity, so that using Ap data would show a similar periodicity.

Over the past years, substantial interest has been developed in the possible existence of periodicities in solar wind parameters and Ap measurements greater than a few years.

In addition, the near-Earth variations in the solar wind, measured by the geomagnetic aa index have been displayed well correlations with the global surface temperature [5, 12, 13].

The 5.1-5.3 year variation found in temperature groups and solar geomagnetic index aa may be attributed to the different paths of the ion particles (cosmic rays).

Similar periodicities of 5-5.2 years in the solar wind speed and ion spectral density were found[10]. While G1, G2, G3, G5 and aa shows the 4.1-4.3 yr period. Finally, we think that 9.5 years in G1, and G3 is due to the true solar-temperature effect and not related to the 11 year solar activity cycle.

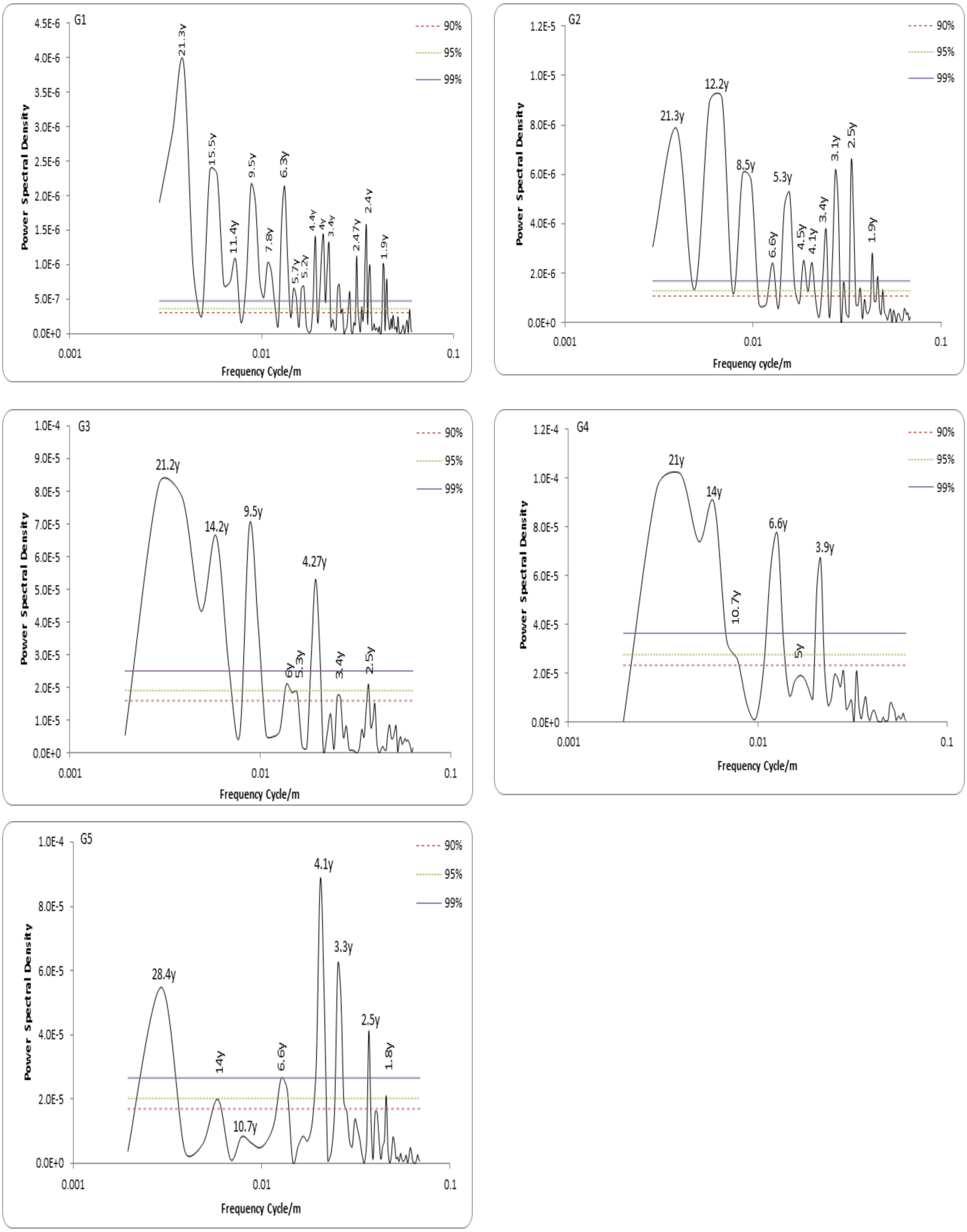

figure 1.7: Power spectral density with the confidence level 90%, 95%, and 99% for each group.

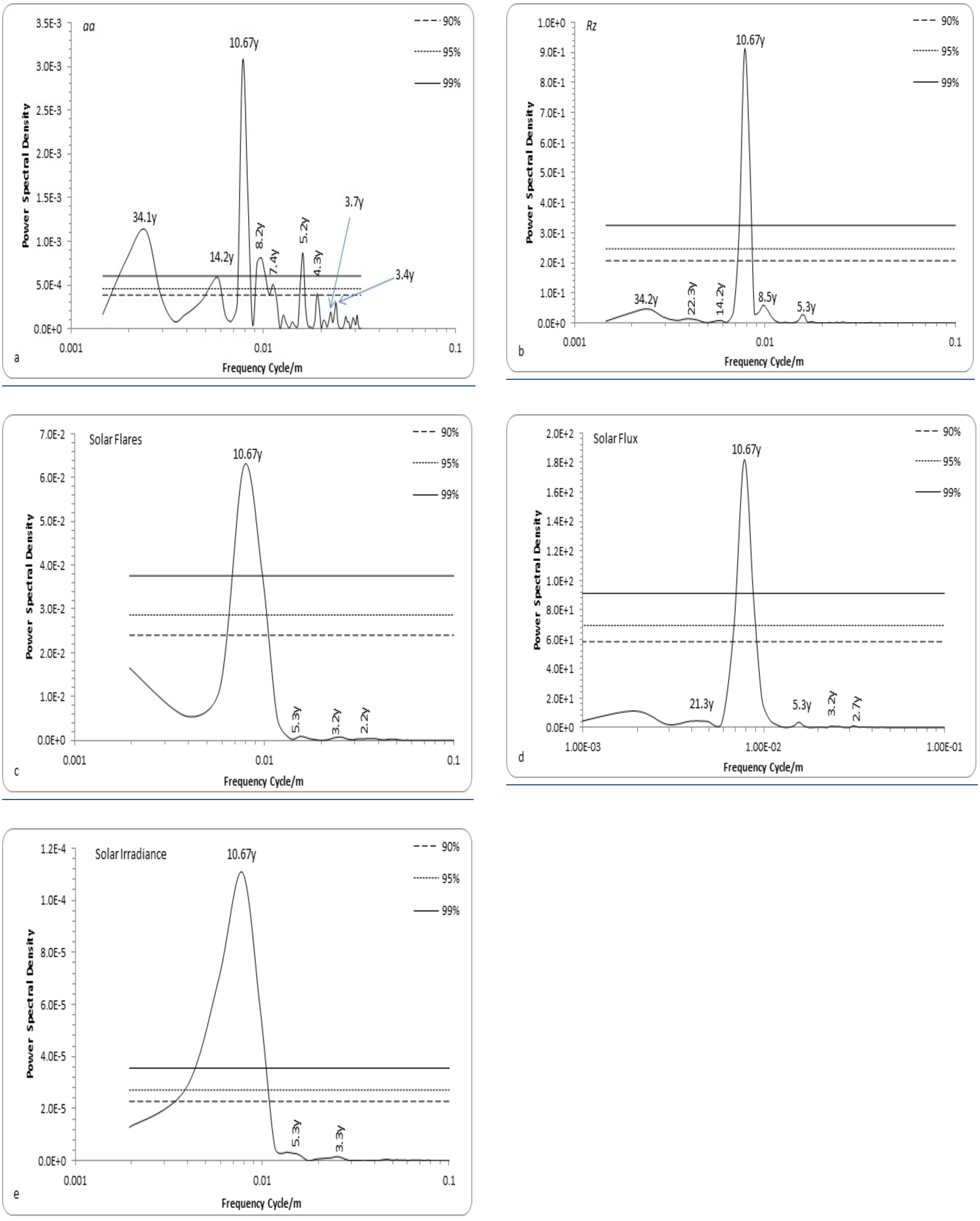

Figure 1.8: Power spectral density with the confidence level 90%, 95%, and 99% for solar indices.

Table-1.3: Observed Spectral Periodicities for the Five Temperature Regions and the Solar Indices throughout the (1880–2004) Period

Periods (Years)	Main periods existence/significance									
	G1	G2	G3	G4	G5	aa	Rz	FI	F10.7	TSI
1.8-1.9	+<99	+<99	+<95	--	+<95	--	--	--	--	--
2.4-2.5	+<99	+<99	+<95	--	+<99	--	--	--	--	--
3.1-4.5	+<99	+<99	+<99	+<99	+<99	--	--	--	--	--
5.2-6.6	+<99	+<99	+<95	+<99	<95	+<99	--	--	--	--
8.5-9.5	+<99	+<99	+<99	--	--	+<99	--	--	--	--
10.7-11.4	+<99	--	--	--	--	+<99	+<99	+<99	+<99	+<99
12.2-15.5	+<99	+<99	+<99	+<99	+<95	+<99	--	--	--	--
21-21.3	+<99	+<99	+<99	+<99	--	--	--	--	--	--
28.2-34.1	--	--	--	--	+<99	+<99	--	--	--	--

CONCLUSION

In this study we try to find out the relation, over a long time period from 1880-2004, between the change in the regional surface temperature and solar-geomagnetic activity represented by the sunspot number Rz, the geomagnetic index aa, solar flares (FI), solar radio flux (F10.7), and total solar irradiance (TSI) and to what degree they are connected. We divided our temperature data into five groups depending on altitude. Cross correlation analysis have been performed between each parameters (aa, Rz, solar flares, F10.7, TSI) and all groups. This analysis revealed that TSI and FI have the greatest effect on the climate change during this period. A small change in energy flux that reached the earth may be played an important role in climate change in such countries. The earlier solar parameters may be partially affecting the present temperatures. The excess of solar energy stored and accumulated for few future months /years in the near-earth system, lead to the temperature variability.

A series of power spectral density (PSD) have been performed for the 12-month running averages for solar indices and all groups from 1880 to 2004. PSD graphs show that the 22 yr solar magnetic cycle (Hale cycle) is more effect on MSAT than solar activity cycle. Some of solar factors contribute as much as 40% of the 1880-2004 regional/global warming. Our results might have progressively play a dominant role in the climate change during the last century; also we suggest that the solar impact on climate change during the same period is significantly stronger than what some theoretical models have predicted.

We conclude that solar variability parameters play an important role in climate change and cannot be excluded from the responsibility of continuous global warming.

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