Solar Forcing on the Changing Climate

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Abstract. The influence of solar cycle and activity phenomena on the two climatic variabilities such as the rainfall and the surface temperature of the Indian subcontinent is critically examined. It is concluded from this study that the sun indeed strongly influences both of these climatic variabilities and the sun's influence simply can not be ignored.

Keywords : *The Sun, Solar Cycle, Solar Irradiance, Indian rainfall, Indian surface temperature*

1.Introduction

From the dawn of the civilization, the sun is revered and held as an awe inspiring celestial object in the sky. In the world, there are many stories and poems woven around the sun god in different folklores and the magnificent architectures are dedicated to the mighty sun. The flora and fauna on the earth mainly depend on the sun for their survival. To sustain the life on the earth, energy is derived from the sun.

Does also the sun sustains and changes the planetary climate in general and the earth's climate in particular? Do physical parameters of the earth's surface or atmosphere vary in consonance with solar cycle and activity phenomena? Yes, the ample evidences from the scientific literature (Reid 1999; Shine 2000; Hiremath and Mandi 2004 and references there in; Georgieva, et. al. 2005a; Georgieva and Kirov 2006; Soon 2006 and references there in; Valev 2006; Haigh 2007; Perry 2007; Feymann 2007; Tiwari and Ramesh 2007 and references there in; Scafetta and West 2008) show that the sun indeed influences the earth's climate and environment. Analysis of vast stretch in time of the paleoclimatic records (Beer, Tobias and Weiss 1998; Muscheler et. al., 2007) show that the sun's activity is imprinted in the global temperature (Georgieva, Bianchi and Kirov 2005 and references there in; Valev 2006) and precipitation variabilities. Owing to proximity of the earth to the sun, one can not neglect sun's influence on the technological and biological systems of the human society (Babayev 2006; Babayev et. al. 2007). As the human society is advancing in space technology and moving in future to other planets, one should know in advance the space weather effects mainly due to the sun.

The earth's global temperature and precipitation such as rainfall-two vital parameters of the climatic system-need to be studied carefully. These two important physical parameters of the global climate affect the human society at large. We have to learn from the past historical records. Some of the scientific evidences show that drastic and catastrophic changes in the climate due to either temperature or precipitation patterns (like the floods and droughts) lead to end of civilizations (example Mayan culture, may be Harappa and Mahenjadaro) on our planet. Until the advent of industrialization, it was believed that the variation of sun's energy output strongly influenced the earth's environment and climate. However, after the industrial era, the anthropogenic influences on the climate are dominating compared to the solar influence. Especially the phenomenal increase of emission of green house gases- like carbon dioxide-mainly contributed by the human beings are recently believed to be attributed to increase in the earth's global surface temperature. As the climate of the Indian subcontinent is strongly related to global climatic variations, from the correlative analysis, it is argued in the present study with the two climatic records of temperature and the Monsoon rainfall of the Indian subcontinent that the sun's influence cannot be ignored and should not be under estimated.

2. Brief Introduction of the Sun

The important physical parameters of the sun are : (i) mass-2 X 10^{30} Kg, (ii) radius-7 X 10^{8} meters, (iii) mean density-1409 Kgm^{-3}, (iv) temperature at the photosphere-5780 K and, (v) the total amount of energy emitted by the sun (i.e., luminosity) measured at one astronomical unit (i.e., distance between the earth and the sun)-3.9X10^{26} joules/sec.

When one takes the cross section of the sun parallel to it's rotation axis, based on the dynamical and physical properties the solar interior can be classified into three distinct zones : (i) the *radiative core* where the the energy is generated by the nuclear fusion of hydrogen atoms and is transferred by the radiation, (ii) the *convection zone* where the energy is transferred from the center to the surface by the convection of the plasma and, (iii) the *photosphere* where the energy is radiated to the space. Above the photosphere, the sun's atmosphere consists of the *chromosphere* and the *corona.* The temperature increases from the layer of photosphere to million degree Kelvin in the corona.

If the sun were static in time with constant output of energy, the planetary environments in general and the earth in particular would have received the constant output of energy at their surfaces. However, the sun's energy output is variable (~ 0.1% in the total irradiance and ~ 10-20% in the UV 200-300 nm) due to spatial and temporal variability of the sun's large scale magnetic field structure, dynamics and flow of mass (both the neutral and charged particles) from the sun. The most outstanding activity of the sun is *sunspots*-cool and dark features compared to the ambient medium-on the sun's surface that modulates the sun's irradiance and the galactic cosmic rays that enter in the planetary environments. The *flares* that are associated with the sunspots (Hiremath 2006) release vast amount of energy (~ 10^{20-} 10^{25} joules) with in a short span of time. The sun also ejects sporadically the mass (~ 10^{15} gm) of plasma to the space and is called *coronal mass ejections*.

There is also a continuous flow of wind (~ 10^{31} charged particles per second or 6-7 billion tons per hour) from the sun towards the space called *solar wind*. The sun's activity varies on time scales of few minutes to months, years to decades and perhaps more than centuries. The 5 minute global oscillations are due to pressure perturbations in the solar interior. The solar different activity indices vary on the time scales of ~ 27 days due to solar rotation and ~ 150 days due to the flares. The ~ 1.3 year periodicity is predominant in different solar activity indices. The next prominent and ubiquitous *viz.*, 11 year solar cycle periodicity is found not only in the present day sun's activity indices but also in the past evolutionary history derived from the solar proxies (such as C^{14} and Be^{10}).

The sun can influence the earth's climate and environment in two ways: (i) by direct influence (Kilifarsha 2006) of the atmosphere (especially the stratosphere and troposphere), the surface and the ocean and, (ii) by indirect influence on the galactic cosmic rays (Bucharova and Valinov 2006). Directly the sun can influence the earth's surface, atmosphere and oceans by its electro magnetic radiation in all the wavelengths. Indirectly the sun mediates the amplitude variation of the galactic cosmic rays that deeply penetrate and ionize the earth's atmosphere leading to formation of the rain drops.

3. Data, Results and Conclusions

In the present study, for the period of 1871-2005, we consider the data of the sunspots and irradiance variations. As for the earth's climate, both the temperature and Indian rainfall variabilities are considered from the website `` http://www.tropmet.res.in" maintained by Rupa Kumar and his colleagues. The Indian rainfall variability has similar characteristics and association with the regional or global circulation parameters. In the present study, we use the seasonal and annual (averaged for the periods of 12 months). For the years 1871-2005, the rainfall data (in mm) is available in monthly and annual series. Where as the sunspot data is obtained from the website `` http://www.ngdc.noaa.gov/STP/SOLAR " and the two data set of solar (total and UV in the wavelength range of 200-295 nano meter) irradiance variabilities are kindly provided by Dr. Lean (Naval Observatory, USA). In Figure 1., the annual sunspot and the Indian rainfall variabilities are illustrated. The solar irradiance (red dotted) and sunspot (blue continuous) variabilities are presented in Figure 2.

In order to assess the influence of the sun on the earth's climate, we perform a correlative analysis. For confirming whether solar influence is different for different seasons on the rainfall variability and following our previous study (Hiremath and Mandi 2004), we classify the data set into four seasons : (i) spring (March-May) rainfall, (ii) south west monsoon (June-Sept) rainfall, (iii) north east monsoon (Oct-Dec) rainfall and, (iv) winter rainfall (Jan & Feb).

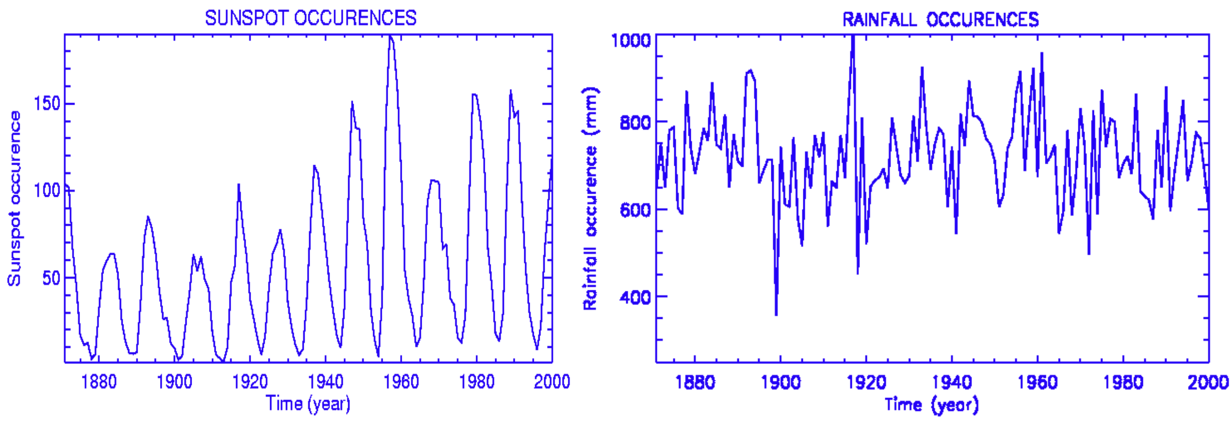

Fig 1., (a) ***Variation of occurrence the sunspot numbers with respect to year. (b) Variation of occurrence of the annual Indian rainfall.***

3.1 Correlative analysis of the solar and rainfall variabilities

In the previous study (Hiremath and Mandi 2004), we performed a correlative analysis of the sunspots and Indian rainfall variabilities for the annual as well as for the seasonal data sets. In

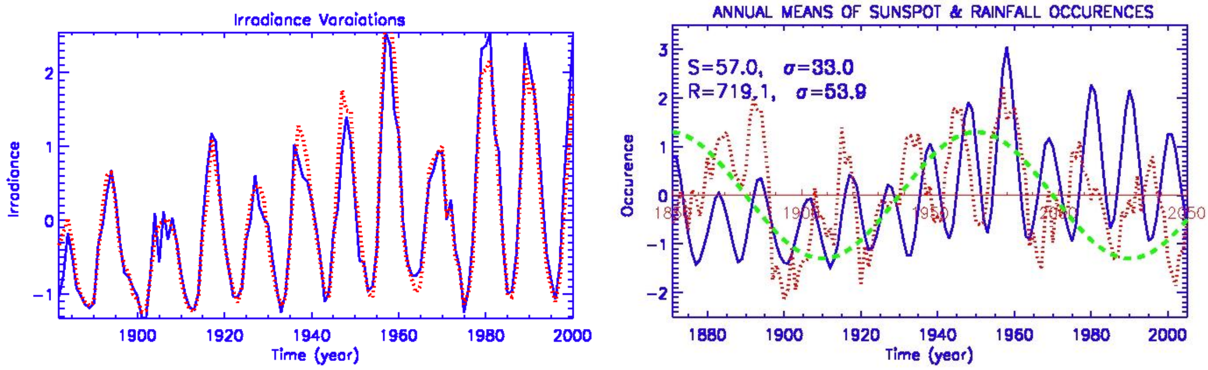

Fig 2. ***The deviation from the mean and normalized to their respective standard deviations of the annual solar and Indian rainfall occurrence variabilities. (a) In the left figure, the blue continuous curve is the occurrence of sunspot number and red dotted curve is irradiance variations(b) In the right figure, blue continuous curve is sunspot occurrence variability and red dotted line is the annual Indian rainfall variability. The green dashed curve is long-term (~ 80-100 years) variation of the annual Indian rainfall variability. S and R are the means of the sunspot and rainfall occurrence variabilities. σ is the standard deviation from the mean of both the variabilities.***

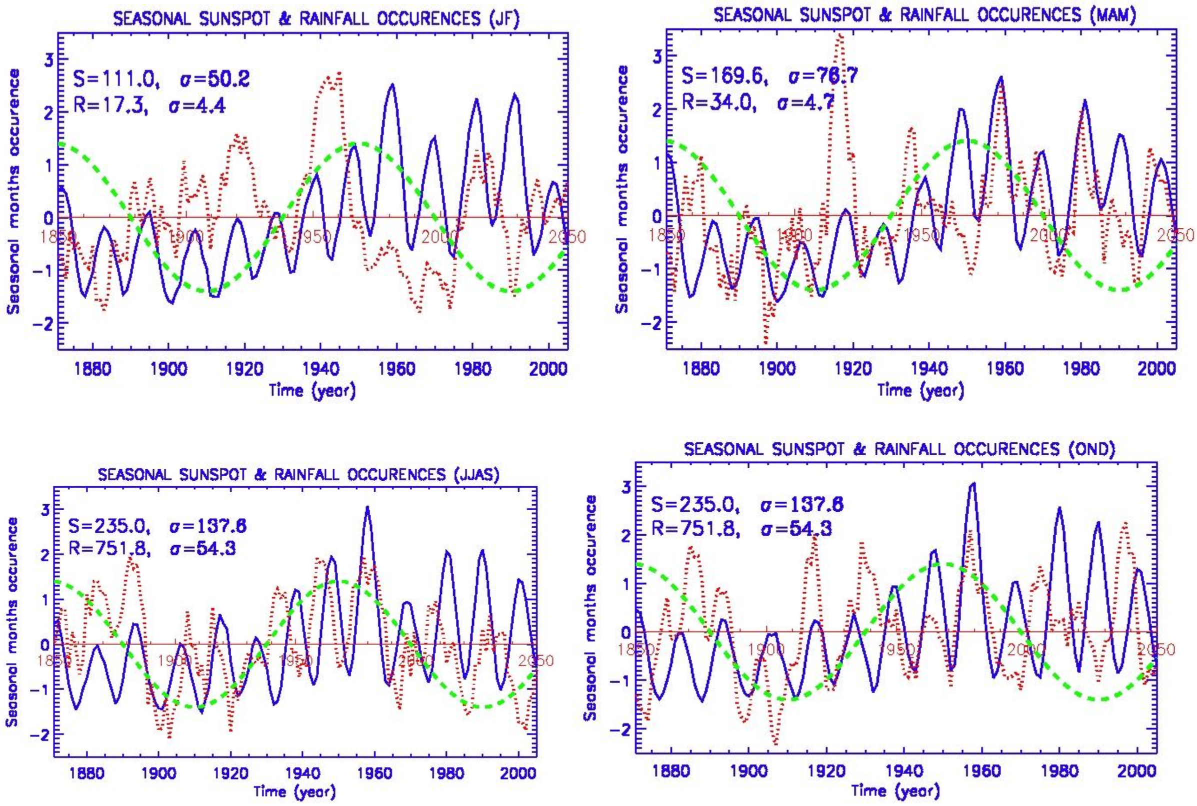

Fig 3. ***The deviation from the mean and normalized to their respective standard deviations of the seasonal sunspot (blue continuous curves) and Indian rainfall occurrence (red dotted curves) variabilities. In all the above four figures, S is the mean of the sunspot activity, R is the mean of the rainfall variability and σ is the standard deviation from the mean for both the variabilities. The green dashed curve is long-term (~ 80-100 years) variation of the annual Indian rainfall variability.***

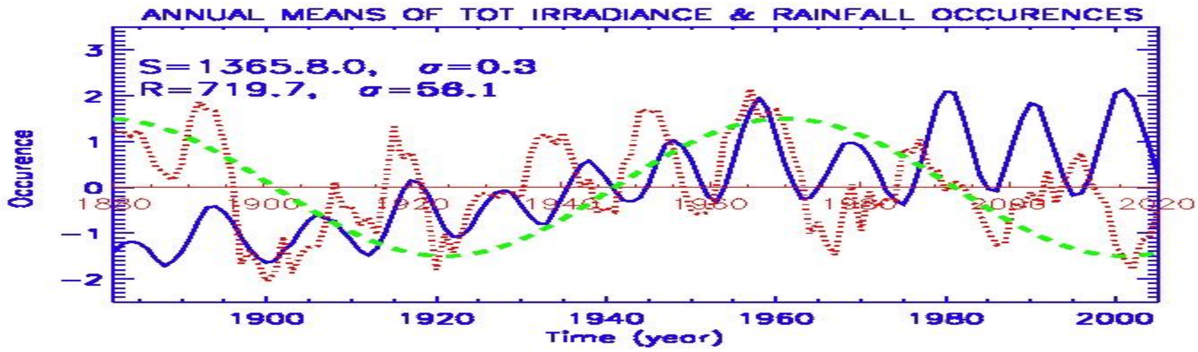

Fig 4. ***The deviation from the mean and normalized to their respective standard deviations of the annual total irradiance (blue continuous curve) and Indian Monsoon rainfall (red dotted curve) occurrence variabilities. S is the mean of the irradiance activity, R is the mean of the rainfall variability and σ is the standard The green dashed curve is long-term (~ 80-100 years) variation of the annual Indian rainfall variability.***

the present study, we extend the data up to the year 2005 and perform the same correlative analysis. As in the previous study for the seasonal sunspot and Indian rainfall variabilities, we obtained a moderate positive correlation (correlation coefficient ~ 30%) for all the seasonal data set and the results are illustrated in Fig 3. We also performed the same correlative analysis for the solar annual total irradiance and the Indian rainfall variabilities. The correlation improves slightly, but not better. In Fig 4., the annual means of total irradiance and the rainfall variabilitis are presented. However, when we perform a correlative analysis for the UV irradiance in the wavelength range of 200-295 nm, especially for MAM and southwest monsoon (JJAS) rainfall veriabilities, we get a very good correlation (~ 60%) and these results are illustrated in Fig 5.

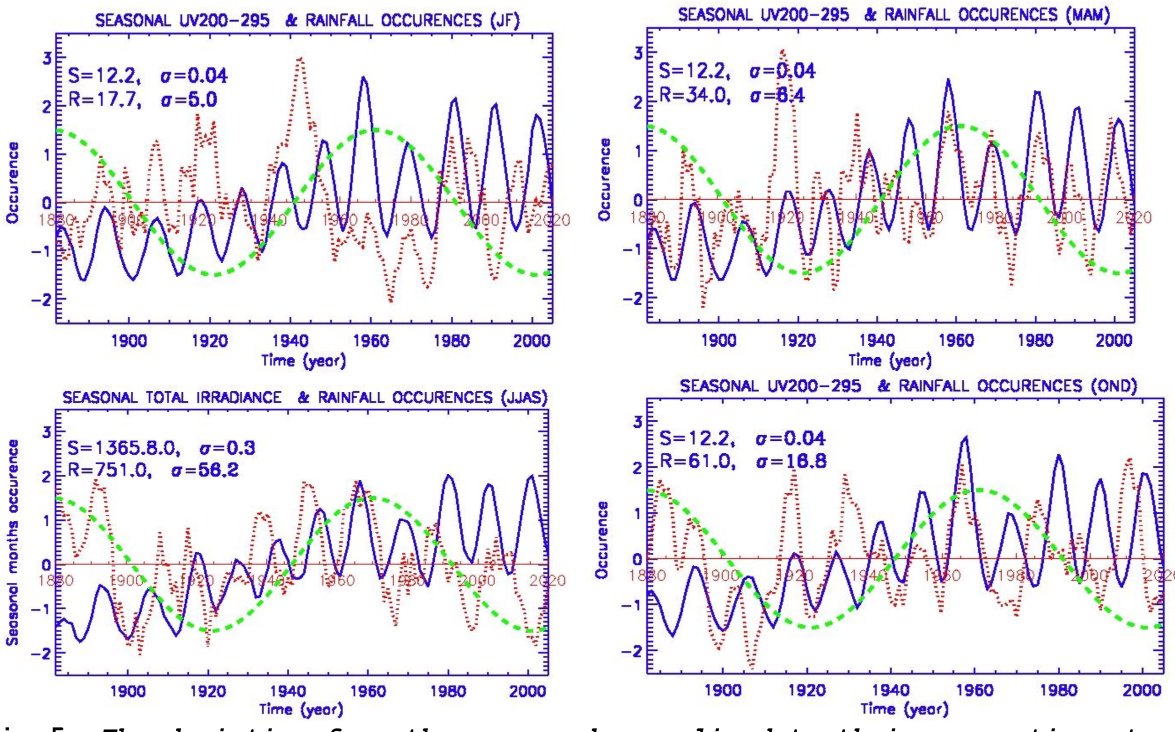

Fig 5. ***The deviation from the mean and normalized to their respective standard deviations of the annual irradiance (blue continuous curve) and Indian Monsoon rainfall (red dotted curve) occurrence variabilities. S is the mean of the***

irradiance activity, R is the mean of the rainfall variability and σ is the standard deviation from the mean for both the variabilities

Although visual inspection of Figures 2(b)-5 between the two solar and rainfall variabilities shows a good correlation, computed and quantitative information such as the correlation coefficient is found to be at most of ~ 60% . More over 1960 onwards rainfall variability is out of phase for both the solar variabilities. This possibly suggests variations of the Indian annual rainfall variability may not be due to annual variation of the sunspot and solar irradiance variabilities. Hence, one should be cautious enough to claim that solar activity overwhelmingly influences the Indian rainfall. However, one should not also be under impression that sunspots and irradiance variabilities are only the main solar activities. One should also check with other solar activity phenomena such as solar wind, coronal holes (Soon et. al. 2000; Georgieva and Kirov 2006) and, coronal mass ejections. Other important reason for the low correlation could be due to not removing of the unknown long term trends in both the rainfall and solar variabilities.

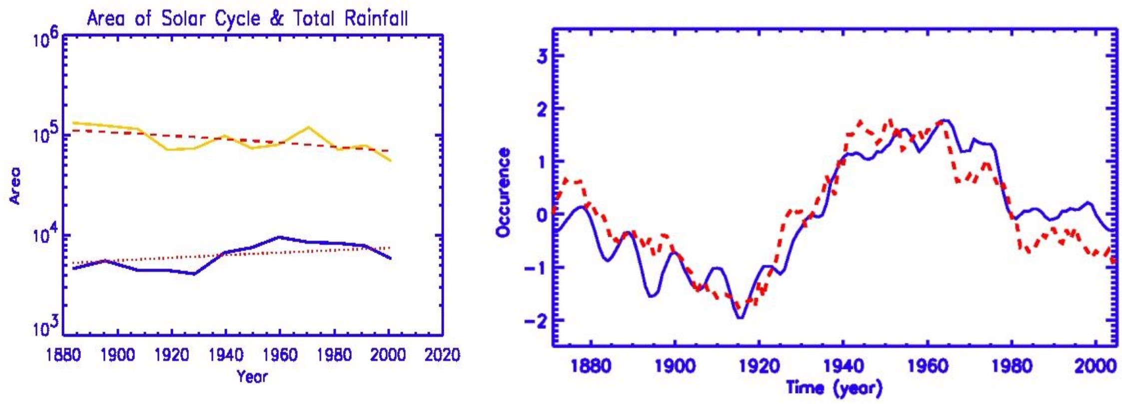

Fig 6. (a) ***The left figure represents the long term variation of areas of the sunspot (increasing trend) cycle and the rainfall (decreasing trend) variabilities. The dotted and dashed lines are the linear least square fit to the respective data,(b) The right figure (by removing long term decreasing trend in the rainfall and increasing trend in the solar activity)illustrates the Indian Monsoon rain fall and sunspot activities. The blue continuous line is the occurrence of sunspot activity, red dashed line is the rainfall variability.***

For the results presented in Fig 2(b)-Fig 5, we removed the annual trends by subtracting respective means and normalized with respect to their standard deviations and came to the conclusion that we did not get very best correlation. Let us probe further whether we get a good correlation incase we remove the decadal variations. In order to remove the decadal variations, following Hiremath and Mandi (2004) and for different periods of the solar cycle, first we compute areas of the solar cycles and then the resulting areas are subjected to the linear least square fit. One can notice from Fig 6(a) (blue curve) that during the period of 1875-2005, there is an increasing trend of the solar activity. The known increasing trend is removed from the smoothened sunspot variability (by taking moving averages of ten years or more from the annual data). Similar procedure for detrending the data is applied to the rainfall variability. From Fig 6(a) (yellow curve), one can notice that there is a long-term decreasing trend in the annual rainfall variability. This long-term decreasing trend is most evident if we extend the present day rainfall variability to the past rainfall variability over hundreds of years back. Both the long-term detrended data are presented in Fig 6(b).When we compute the correlation coefficient of the smoothened long-term detrended data of both rainfall and sunspot data, we get a very good correlation of ~ 80-90% (with high significance) depending upon moving average intervals of 10-22 years. Thus we can safely conclude that, on long-term scale (when moving average of 10 or more years is considered), sun indeed influences the Indian rainfall activity. Owing to strong solar influence on the Indian Monsoon variability and predictive capability of future solar activity cycles (Hiremath 2008), one can predict the long-term Indian rainfall variability by 10-100 years in advance.

3.2 Correlative analysis of the solar and temperature variabilities

In order assess the solar influence on other climatic variability of the Indian subcontinent, we consider the available (1901-2003) maximum, minimum and difference between the maximum and minimum (that represents the earth's albedo) temperature variabilities. As described in the previous section, we compute the deviation from the mean and then normalized with respect to their standard deviations.

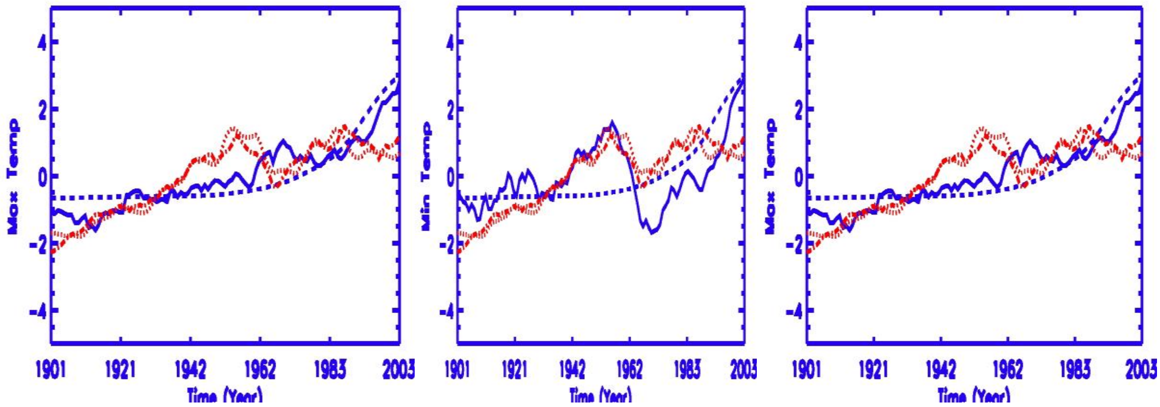

Fig 7. The deviation from the mean and normalized to the respective standard deviations of the temperature of the Indian subcontinent, Asian atmospheric concentration of carbon dioxide and solar activity variabilities. The blue continuous line is surface temperature of the Indian subcontinent, blue dashed line is concentration of carbon dioxide, red dotted line is solar UV irradiance and red dash with dotted line is geomagnetic aa index. All the three figures (figure 7(a), fig 7(b) and fig 7(c)) illustrate the maximum, minimum and (maximum-minimum) temperature variabilities over plotted with the solar activity indices.

As the increase in the global warming is believed to be related with increase in the concentration of the atmospheric carbon dioxide, for the sake comparison, atmospheric carbon dioxide (http://cdiac.esd.oml.gov) of the Asian continent is considered. As for the solar activity indices, we consider not only the sunspot and UV irradiance data but also occurrence of geomagnetic aa index-supposed to be the indicator of solar activity (Georgieva and Kirov 2006)-is considered. Consideration of the geomagnetic aa index for this correlative analysis basically also is influenced by the previous similar studies (Goergieva, Bianchi and Kirov 2005; Georgieva, Kirov and Bianchi 2005c). In Fig 7., with different solar activity indices, we present the surface temperature of the Indian subcontinent and the atmospheric carbon dioxide of the Asian continent. One important conclusion from this illustration is that, similar to global warming, Indian subcontinent is also warming substantially especially after 1980 onwards. One can also find the similar trend of the atmospheric carbon dioxide of the Asian continent. Although visual inspection and computation of the correlation coefficient appear to yield a very good correlation between the temperature and carbon dioxide variabailities, one can not explain the annual and decadal variations of the temperature variability. This is because increase in the atmospheric carbon dioxide variability, especially after 1980, is very smooth compared to either temperature or solar activity variabilities.

Following are other important results from this correlative study between the temperature of the Indian subcontinent and the solar activity indices: (i) after year 1980 onwards, compared to variation with the solar activity phenomena, although there is a strong correlation between the variation of maximum temperature with the variation of concentration of carbon dioxide in the atmosphere of the Asian continent, the records of variation of minimum temperature and difference between maximum and minimum temperature records (that represents the earth's albedo) vary strongly with the solar activity, (ii) six year lag of maximum temperature variation data with the variation of solar activity data also yields a strong correlation and, (iii) there is a linear increasing trend or pattern in the variation of concentration of carbon dioxide in the century scale data, (iv) on the other hand, in addition to increasing linear trend, there are superposed annual and decadal variations in the surface temperature data whose amplitude variations are almost similar to amplitude variations of the solar activity. From all these four results, one can safely conclude that the solar activity also strongly influences the surface temperature variability of the Indian subcontinent. Overall conclusion from the previous and present sections is that *there is a strong forcing on the changing climate of the Indian subcontinent.*

4. Conclusions

In order to assess the influence of solar activity on the climate of the Indian sub continent, two variabilities data such as rainfall and temperature are considered for the present analysis. Correlative analysis between the solar activity indices and two climate variabilities of the Indian subcontinent suggests that there is a strong solar forcing on the changing climate of the Indian subcontinent and it can not be simply ignored.

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