Influence of the solar activity on the Indian Monsoon rainfall

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Abstract

We use 130 years data for studying correlative effects due to solar cycle and activity phenomena on the occurrence of the Indian Monsoon rainfall. We compute the correlation coefficients and significance of correlation coefficients for the seasonal and the annual data. We find that: (i) for the whole years 1871–2000, the spring and southwest monsoon rainfall variabilities have significant positive correlations with the sunspot activity during the corresponding period, (ii) the FFT and the wavelet analyses of the southwest monsoon rainfall variability show the periods 2.7, 16 and 22 year, respectively (similar to the periods found in sunspot occurrence data) and, (iii) there is a long-term trend indicating a gradual decrease of occurrence of rainfall variability by nearly $2.3 \pm 1.3$ mm/year and increase of sunspot activity by nearly $3.9 \pm 1.5$ sunspots/year compared to the activity of previous solar cycle.

We speculate in this study a possible physical connection between the occurrence of the rainfall variability and the sunspot activity, and the flux of galactic cosmic rays. Owing to long-term positive and significant correlation of the spring and southwest monsoon rainfall variabilities with the sunspot activity, it is suggested that solar activity may be included as one of the crucial parameter in modeling and predicting the Indian monsoon rainfall.

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1. Introduction

India is predominantly a agricultural country whose economy depends mainly on the Monsoon rainfall. Vagaries of Monsoon rainfall lead to floods and droughts resulting in many loss of lives and valuable cattle population, destroying of standing crops, etc., estimated to be in billions of rupees. Cause for the abnormal variabilities of the Monsoon rainfall such as occurring of floods and droughts is not yet completely understood. It is believed that the main causes are due to the localized anthropogenic influences over the climate and environment, viz., degradation of forest coverage, silting of dams and other unknown
causes (Parthasarathy et al., 1993, and references there in; Rupa Kumar et al., 2002; Gadgil, 2003).

Another cause that is clearly discernible in most of the recent findings is the solar radiative forcing over the global climate and the environment of the earth. Overwhelming evidence is building up that the solar cycle and related activity phenomena have a good correlation with the Earth’s global climate and temperature (Eddy, 1977; Friis-Christensen and Lassen, 1991; White et al., 1997; Soon et al., 1996, 2000a,b; Baliunas and Soon, 1996; Parker, 1999; Baker, 2000; Lean and Rind, 2001; Pulkkinen et al., 2001; Rozelot, 2001; Solanki, 2002; Soon and Yaskell, 2003; Tsiropoula, 2003; Tan et al., 2004), the earth’s albedo (Goode et al., 2003), the sea surface temperatures of the three (Atlantic, Pacific and Indian) main ocean basins (Reid, 2000; Haigh, 2001; Bond et al., 2001), and the galactic cosmic ray flux (GCR) with the Earth’s cloud cover (Svensmark, 1988; Marsh and Svensmark, 2000). For the association between the sunspot numbers and the Monsoon rainfall variability, many studies (Ananthakrishnan and Parthasarathy, 1984; Parthasarathy et al., 1993, and references there in; Jain and Tripathy, 1997) show a moderate to strong correlation. Very recent study (Neff et al., 2001) of the analysis of record of oxygen isotope – a proxy for variations in the tropical circulation and monsoon rainfall variations from the period 9.6 to 6.1 kyr before present day – shows decadal scale variations (∼10–22 years, a possible signature of the sunspot and the solar magnetic activity) in the monsoon activity. Thus it is very important to study the influence of the solar cycle and activity phenomena on the climate and environment of the earth, in general, and the monsoon rainfall variability in particular.

Aim of the present study is to search for a possible association between the sunspot activity and the Indian Monsoon rainfall variability. We assume that there may be an unknown physical phenomenon between the rainfall variability and the solar activity. Similar physical studies of solar forcing on the rain formations are scarce. However, a study (Rogers, 1990, and references there in) shows that the rain formation is a function of different physical parameters of macro- and microphysics. The important parameter from the macrophysics is the ambient temperature where clouds reside and formation of rain drops occur due to process of spontaneous coalescence and accretion. Since cloud and rain formations are function of ambient temperature, it is more likely that the temporal variations of rainfall on 11 years time scale may be due to temporal variation in forcing of the solar radiation. It is well established from the satellite observations that the sunspot activity shows a similar temporal behavior as that of irradiance variations (Wilson and Hudson, 1988, 1991; Frohlich, 2000; Lean, 2001). Assuming that such correlation between the sunspot and the irradiance activities may exist before the era of satellite observations, we consider the occurrence activity of the sunspot data for the present correlative analysis.

Though, correlative studies between the sunspot numbers and the annual Indian Monsoon rainfall have been undertaken previously (Ananthakrishnan and Parthasarathy, 1984, and references there in), some of the finer aspects such as correlation between the seasonal data, significance of correlation coefficients and periodic behavior of the rainfall variability that may be related with the sunspot activity is being considered in the present study.

In Section 2, we present the data used and different methods of analysis. Long-term variation of influence of the solar activity on the rainfall variability is presented in Section 3. The periodic behaviors of the rainfall variability and the solar activity are presented in Section 4. In Section 5, we present long-term variations of the sunspot activity and the rainfall variability. In Section 6, we present the discussion and conclusions.

2. Data and analysis

We consider 130 years (1871–2000) data of the sunspot numbers and the Indian Monsoon rainfall (Parthasarathy et al., 1993; http://www.tropmet.res.in) occurrence variability for correlative and periodic analyses. Parthasarathy et al. (1993) have compiled a homogeneous set of rainfall data from the 14 meteorological subdivisions covering
the north western and central parts of India (about 55% of the total area of the country). This rainfall variability has similar characteristics and associations with the regional or global circulation parameters. The genesis and the salient features of the monsoon rainfall activity in the past and the present time periods can be found from the recent reviews (Cadet, 1979; Rupa Kumar et al., 2002, and references there in; for the probable connection with the solar activity also see the papers Njau, 2000a,b). For the years 1871–2000, the rainfall data (in mm) is available in monthly, seasonal and annual series. In the present analysis, we use the seasonal (including the spring, the southwest, the northeast and the winter monsoon) and the annual (averaged for the period of 12 months) rainfall data. We give different nomenclatures for the seasonal rainfall occurrences as follows. We combine the winter rainfall data for the months of January and February and denote as \( JF \). For the combined months of the March, April and May, spring rainfall dataset, we denote as \( MAM \). In rest of the months, the rainfall variability is dominated by the southwest (June, July, August and September) and northeast (October, November and December) monsoons which we denote as \( JJAS \) and \( OND \), respectively. The technical definition of the monsoon is a seasonal reversal in the prevailing wind direction. It is most often applied to the seasonal reversals of the wind direction along the shores of the Indian ocean that blow from the southwest during the months of \( JJAS \) and from the northeast during the months of \( OND \). The reversal of the monsoon winds is mainly due to the differential heating between continental areas and the oceans as a result of the zenithal march of the sun (Cadet, 1979). We also give similar nomenclatures (i.e., \( JF, MAM, JJAS \) and \( OND \)) for the combination of the sunspot occurrence data. For the same years (1871–2000), we use the sunspot occurrence data from the National Geophysical Data Center, Boulder, Colorado, USA (http://www.ngdc.noaa.gov/STP/SOLAR/SSN/ssn.html).

Following methods are used to know the influence of solar activity on the rainfall variability: (i) using correlative analysis, we study the long (>1 year) term influence of the solar activity and, (ii) both the datasets are subjected to the Fourier and the wavelet transforms for detecting periodicities. If periods detected in the rainfall variability are almost similar to the periods detected in the sunspot activity, we can safely conclude that the solar activity indeed influences on the rainfall variability. In Fig. 1, we illustrate the yearly means of the rainfall (in mm) and the sunspot occurrences, respectively.

3. The long-term variation of influence of the solar activity

In order to know the long-term influence of solar activity on the rainfall variability, for the annual raw data (1871–2000), we compute the Spearman Rank-Order correlation coefficient and its significance (Press et al., 1992a) between occurrences of the sunspot activity and the rainfall variability. This method of finding the correlation between two variabilities is more robust than the usual method (i.e., by linear correlation). These
results are presented in Table 1. In this table, the first column represents abbreviations for the seasonal and annual data, the second column represents the correlation coefficient ‘r’, the third column represents the significance of correlation coefficient, the fourth to eighth columns are the coefficients and uncertainties with the relevant significant of $\chi^2$ obtained from the linear least square fit between the sunspot and the rainfall occurrences. From the last row of Table 1, we find that for the annual data, solar activity is positively correlated with a high significance. Some times either very high correlation or the low correlation with very high significance is misleading to make any meaningful conclusions from the analysis. For this purpose one has to test whether the relation is a casual or causal effect. When we say the causal effect, it means that, physics behind the influence of the solar activity on the rainfall variability. Unfortunately, we do not know the actual causal effect. On the other hand, the casual relation can be tested as follows.

We know (Fisher, 1930; Elmore and Woehlke, 1996), while deriving the correlation coefficient, that both the variabilities must be linearly related and we should get a good least square fit for the linear relationship of the form $y = A + Bx$, where $x$ is the sunspot activity, $y$ is the rainfall variability and, $A$ and $B$ are the coefficients to be determined. From such a linear relationship and using both the annual dataset, we get constant coefficients (see the fourth and the sixth columns of the last row in Table 1) with large uncertainty in the first coefficient ($A$) and very low probability of the $\chi^2$. This shows that the mean yearly rainfall and sunspot occurrence data do not show any correlation at all. The obvious reason must be a combination of different seasonal rainfall variabilities, viz., the spring, southwest monsoon, northeast monsoon and the winter rainfall that may have different characteristics of the occurrences used for the correlative analysis.

We separate these seasonal rainfalls for testing any good correlation with the sunspot activity. For both the seasonal datasets, after combining the monthly datasets for a particular year, we compute means and standard deviations (SD). Since seasonal rainfall dataset is noisy, we smooth the same by four points moving average. In Fig. 2, we present the seasonal rainfall (dotted line) variability and the sunspot (continuous line) activity. For easy comparison of the two datasets, in Fig. 2, the data is presented as a deviation from the mean and then is normalized to their respective SD.

Some of the following interesting results can be inferred from the analysis. For all the seasonal months, from the year 1871 to around the year 1940, the sunspot occurrence activity is deviated either negatively or later on positively from overall mean. Interestingly, except the winter and the northeast monsoons, the spring and the southwest monsoon rainfall variabilities have almost similar trends as that of the seasonal sunspot activity. The second important result is that the amplitudes of the solar activities are different in different seasonal months. This result is also true in case of the rainfall variabilities except that ‘for different solar cycles, the amplitude of rainfall occurrence deviations are small when the amplitude of the sunspot activity is large’ and vice versa (see for example, in discussion, a possible physical connection between the rainfall, sunspot and GCR activities). Results of the correlation coefficients for the seasonal months are presented in Table 1. Note from the table that in all respects (i.e., a high correlation with high significance, small uncertainties (\( \sim 15\))
50%) in A and B coefficients and very high significance of the least square fit), the spring and the southwest monsoon rainfall occurrences have a very good positive correlation with the sunspot activity during those seasonal months. On the other hand, the winter and the northeast rainfall variabilities are not correlated. Presently, it is very difficult to understand these opposite behaviors of both the seasonal rainfall variabilities.

We also compute phase lag/lead of the correlation coefficients. Following the method of IDL software package, we compute the correlation coefficient for different phase lags as follows. Let \( L \) be the phase lag in years, then for negative \( (L < 0) \) phase lag we have the correlation coefficient \( R_1 = N_1/D^{1/2} \), where

\[
N_1 = \sum_{k=0}^{N-1-L} [(x_{k+L} - \bar{x})(y_k - \bar{y})] ,
\]

\[
D = \sum_{k=0}^{N-1} (x_k - \bar{x})^2 [\sum_{k=0}^{N-1} (y_k - \bar{y})^2] \quad \text{and for the positive and zero } (L \geq 0) \text{ phase lag we have the correlation coefficient } R_2 = N_2/D^{1/2}, \]

where
The variables $x$ and $y$ represent the sunspot and rainfall variabilities and, $\bar{x}$ and $\bar{y}$ represent their respective means. From this method, we get (with high significance) a good correlation coefficient for all the seasonal variabilities especially for the lag in the range of 1–3 years. These results are presented in Fig. 3. Presently, we cannot understand why the rainfall variability is lagging by 1–3 years behind the sunspot activity.

4. Periodicities in the occurrence of solar and rainfall variabilities

We assume that the solar activity influences the rainfall variability. That means irrespective of physical origin of the rainfall activity, the local perturbations in the atmospheric and meteorological conditions may lead to waves and oscillations resulting in periodic behavior of the rainfall variability. In order to maintain such periodic rainfall activity, either local or external forcing is necessary. Except the local phenomenon (El Nino oscillations) whose periodicity is in the range 3–6 years, one can not explain other periodicities detected from the following periodic analysis of the rainfall variability. Thus, one can safely assume that the external periodic forcing to the earth’s atmosphere may be the sun that manifests itself with many periodicities in the solar variabilities. For example, 27-day period due to sun’s rotation, 11 year sunspot occurrence activity and, 22 year magnetic activity are some of the dominant periodic variabilities on the sun (Stenflo and Vogel, 1986; Hiremath, 1995; Javaraiah and Gokhale, 1995; Javaraiah and Komm, 1999, and references there in). Let us know whether, from the following analysis, we get similar or very near such periodicities in the rainfall variability.

We search periodicities in both of the occurrences from the two important techniques viz., ‘the Fourier transform and the wavelet transform’, respectively. From the former technique, one can get the accurate periods. However, from the latter technique, one can get not only approximate period but also one can understand whether time series is a stationary or non-stationary one. In the following study, first we detect the periodicities using the Fourier transform and confirm their stationarity with the wavelet transform.

Since the periodicities of the sunspot activity are well known, we do not subject the sunspot occurrence data to both the FFT and the wavelet transform. For detecting long-term (> 1 year) periodicities in the rainfall variability, with equal interval of 1 year and for the period of 1871–2000, we use the seasonal southwest monsoon rainfall data which is very well correlated with the sunspot activity. From the raw data, first we compute the running mean using Savgol filter (Press et al., 1992b). By subtracting the running mean from the raw data, we obtain detrended data. The resulting data then is subject to Fast Fourier transform (FFT) and power spectrum is presented in the upper panel of Fig. 4. Note that all the periods which have greater than $3\sigma$ levels of power are marked just above the peaks in the power spectrum. It is interesting to note that both the detected periods (16 and 22 years) are also found in the FFT analysis (Currie, 1973, and references there in) of the sunspot occurrences. The similar periodicity (22 years) is also found in the Monsoon rainfall variability data (for all India annual data, see Ananthakrishnan and Parthasarathy, 1984; for different stations and for the annual rainfall data, see Alvi and Koteswaram, 1985; for the sub tropical region (Udaipur) of India, see Jain and Tripathy, 1997) and in other parts of the world’s rainfall data (Hoyt and Schatten, 1997). We also performed FFT analysis for the other well correlated rainfall variability, the seasonal spring data. We find that 6.5 and 3.7 year are the dominant periods which have powers greater than $3\sigma$ level. Whereas 16 and 22 year peaks have powers less than $2\sigma$ level. Thus this analysis shows that among four seasonal variabilities, owing to detection of more periods (may be of solar origin), the southwest monsoon rainfall variability is strongly influenced by the solar activity.

The period 2.7 years in the power spectrum of rainfall variability may be due to well-known QBO (Quasi-biennial oscillation) phenomenon in the earth’s atmosphere which in turn might have been influenced by the solar activity (Elias and Marta, 2003, and references there in). The QBO is de-
scribed (Angell and Korshover, 1964) as the phenomenon of reversal of wind directions in the equatorial stratosphere. For about one year the prevailing wind direction is easterly while during the following year it is westerly.

From the FFT analysis, we cannot judge that the sun continuously influences such periodic behavior over the rainfall variability. In order to know the continuous influence of the sun, we subject the rainfall variability data with the wavelet transform whose power spectrum is presented in the lower panel of Fig. 4. The wavelet power in the hatched area is not significant due to the fact that the data has been padded with zeros before applying the wavelet spectrum. It is crucial to be noted that all the periodicities detected from the Fourier analyses are also present in the wavelet power spectrum (concentrations of the wavelet power in the interior regions of contours, which are significant at 90% confidence levels). One disadvantage of the wavelet power spectrum is that we cannot separate the periodic structures as in usual FFT method. Except 79 year periodicity, the wavelet analysis (Kailas and Narasimha, 2000) of Indian monsoon rainfall data for the period of 1871–1990 shows the similar periods.

From the power spectrum of the rainfall variability, one may conclude that the 2.7 year (may be due to QBO phenomenon in the earth’s atmosphere) period which has significant power compared to 16 and 22 years (may be due to of solar origin) is controlling the Indian monsoon rainfall variability. This conclusion can not be supported from the following arguments. First, the periods around 2–3 years are also found from the FFT analysis of the solar activity (Schuster, 1906; Apostolov and Letfus, 1955; Shapiro and Ward, 1962; Sakurai, 1981; Singh and Prabhu, 1985;
Djurovic and Paquet, 1993; Bazilevskaya et al., 2000; John, 2003). Hence, the solar activity may be controlling the rainfall variability through the earth’s atmospheric QBO phenomenon. Secondly, one can notice from the wavelet spectrum of the rainfall variability that the periods around 2–3 years are not as persistent as the period around 11–22 years. Thus both the arguments lead to the following important conclusion that ‘the sun indeed influences 2–3 years to decadal scale periodicities on the occurrence of the Indian rainfall variability’.

5. The long-term variation of the areas of the sunspot and the rainfall occurrences

In order to explore further the long-term association between the sunspot and monsoon rainfall variabilities, we combined all the annual dataset for each cycle and computed areas of the solar cycle. We define *length of the solar cycle* as the total number of years between min–min. In the previous study (Friis-Christensen and Lassen, 1991), length of the solar cycle is considered as an important variable for study of the correlative analysis. However, one can notice from Fig. 1. (lower panel) that different solar cycles have same length of periods for the occurrence of different sunspot numbers. This shows that the solar activity is a function of two variables, viz., the length and the amplitude (the number of occurrence of sunspots) of the solar cycle during a particular period. We call this function of solar activity as *area of the solar cycle* and define as a product of summation of the sunspot occurrences during min–min and length of the solar cycle. Similarly, we also define *area of the rainfall occurrence variability* as a product of summation of the rainfall occurrence variability during min–min and length of the solar cycle. In a way, both the areas represent the total fluxes of occurrences of the sunspot and the rainfall variabilities during the 11 year solar cycle period.

In top panel of Fig. 5, we present areas of the solar cycle and the areas of the rainfall variability. Owing to unavailability of measuremental errors in both the datasets, we consider square root of both the observed occurrence areas as errors in each points and the uncertainties in the coefficients are computed. If *Cycle* is the area of the solar activity, *Rain* is area of the rainfall variability and, *T* is the time of observations, then the linear relations from both of the least square fits are given as follows:

\[
\text{Cycle} = (-38.80 \pm 15.34) + (0.0200 \pm 0.0079)T
\]

(1)

and

\[
\text{Rain} = (29.97 \pm 17.52) - (0.0155 \pm 0.0090)T.
\]

(2)

The confidence levels of both the least square fits are 95.8% for the solar cycle area and 67% for the rainfall area variabilities, respectively. For both the set of data, we compute correlation coefficient that is found to be 0.027 with very low significance (6.3%). The large uncertainties in the coefficients determined from the least square fit and the low (and insignificant) correlation coefficient suggests that one should need measuremental errors in order to make any definite conclusion regarding long-term association between areas of the sunspot activity and the rainfall variability.

The results from Eqs. (1) and (2) enabled us to determine the following long-term trends in the rainfall and the sunspot variabilities, respectively: (i) from 1871 onwards, the sunspot activity is increasing at the rate of approximately 39.0 \pm 15.0 units of the area from one solar cycle to another solar cycle or by considering average length of the solar cycle to be 10 years, the sunspot activity of the particular cycle is increased nearly by 3.9 \pm 1.5 sunspots/year compared to the previous cycle; (ii) correspondingly the rainfall variability is decreasing at the rate of approximately 23.0 \pm 13.0 units of the area from one solar cycle to another solar cycle, or, the rainfall variability of a particular solar cycle is reduced by 2.3 \pm 1.3 mm/year compared to the previous solar cycle.

In the lower panel of Fig. 5, we present the data that have been detrended and normalized to their respective maximum areas. It is important to note that association between the rainfall and the sunspot area variabilities is very strong. The correla-
tion coefficient with a very high significance (96%) is found to be 0.62. The results presented in this section and in Section 3 suggest that both the sunspot and the rainfall variabilities consist of long-term “steady parts” with the opposite behaviors (that have feeble correlation) and “fluctuating parts” with the almost similar behaviors (that have strong positive correlation).

6. Discussion and conclusions

The long-term positive correlation between the occurrences of the two variabilities suggests the unknown causal relationship. On the other hand, the inverse relationship (the amplitude of rainfall occurrence variability is small when the amplitude of the sunspot activity is large, see Section 3) between both the variabilities during a particular period of the solar cycle can be understood as follows. The recent satellite observations (Svensmark, 1988; Svensmark and Fris-Christensen, 1997; Marsh and Svensmark, 2000; Palle and Butler, 2000, 2001) show that there is a positive correlation between the cloud cover in the Earth’s atmosphere and the flux of the GCR. Since flux of the GCR is anti-correlated with the sunspot activity, one would also expect a similar relationship.
between the amplitudes of the rainfall and the sunspot variabilities as we obtained from the present study. The GCR activity is the source of ions in the earth’s atmosphere. We know that the condensation of water vapor into water drops is mediated by the ions in the atmosphere. Thus any change in the GCR activity correspondingly affects the rainfall variability. To put it in a precise way, as the intensity of the GCR is inversely proportional to the solar activity, increase in solar activity results in reducing the intensity of the GCR flux. This ultimately results in both reducing the activity in nucleation of the cloud particles and suppression of the rainfall variability (Parker, 1999).

Though the long-term (>100 years) association between the steady part of areas of the sunspot activity and the rainfall variability appears to be feeble, one may think of following possible scenarios of the physical connection between the long term decrease in the rainfall variability and a steady increase in the solar activity.

It is crucial to be noted that the result of increasing sunspot activity is reminiscent of the increase in global sea-surface and land-surface temperatures of the earth. Thus, one may wonder whether the long term decrease in the rainfall variability is either due to long term increase in the global earth’s sea surface temperature (which is believed to be due to anthropogenic influences that result in increasing the concentration of carbon dioxide in the atmosphere) or due to effect of solar activity. These effects can be delineated from the recent simulations (Zhao and Kellog, 1988; Meehl and Washington, 1993; Hu et al., 2000) which show that as the concentration of carbon di-oxide in the atmosphere increases, correspondingly, the rainfall variability increases from the beginning of the 19th century. This simulations result is clearly against the observed rainfall variability obtained from the present study and from the previous study (Dugam and Kakade, 1999) which show a strong inverse relationship between the monsoon variability and the tropical belt temperature that in turn could be related with the increased long-term solar activity.

There are studies (Toon, 2000; Rosenfield, 2000) which show that a steady increase of the anthropogenic pollution in the earth’s atmosphere suppresses the precipitation that may affect the long-term rainfall variability. However, it is more likely from the following reason and argument that, long term decrease in the rainfall variability may be due to increase of pollutants of natural origin. During the pre-monsoon season, the Arabian sea is mainly loaded with the enhanced aerosols (Sateesh and Srinivasan, 2002) such as sea salts, etc., of natural origin. If we assume that increase of sea and land surface temperatures may be due to feeble solar signal, correspondingly, there may be increase of concentration of the aerosols of natural origin in the atmosphere resulting in suppression of the long-term rainfall variability. Moreover, by the fact that Monsoon rainfall variability is connected with the global precipitation, the decrease of the rainfall variability from 1871 onwards is also consistent with the decrease of the global mean precipitation (Hulme et al., 1998). Hence, ‘it is unlikely that long term decrease in the rainfall variability is either due to increase of the concentration of carbon dioxide in the earth’s atmosphere or due to increase of pollutants of anthropogenic origin’. Other possible strong variabilities, viz., ENSO (Ashrit et al., 2001) may also be effective to influence on the rainfall variability. However, some other studies (Krishna Kumar et al., 1999) show that ENSO is not influencing the rainfall variability. Over the period of 100 years, as sunspot activity increases (Lockwood, 2002) there will be a corresponding increase in the intensity of the solar irradiance variations (Lean, 2001, and references there in). The increase in the solar irradiance variations influence the ambient temperature of the earth’s atmosphere and ultimately influencing the rainfall variability. Hence, more likely possibility is influence of the sun and the solar activity phenomena on the Monsoon rainfall variability. This conclusion can also be strengthened from the present and the previous (Kailas and Narasimha, 2000) periodic analyses which show that the periodicities in the occurrence of rainfall variability are almost similar to the periodicities in the sunspot occurrence activity.

However, over the short- and the long-term periods, it is interesting to know the actual physical phenomenon that relates the variations of...
feeble flux of solar irradiance variations, concentration of the aerosol particles of natural origin, the flux of GCR all of which may influence on the formation of rain drops and hence rainfall variability.

From the results presented from this study and the ideas presented in the discussion, we suggest to include the solar activity (especially the sunspot occurrences) as one of the important parameters in long range forecasting (LRF) model that is currently used by the India Meteorological Department (IMD) for predicting the Indian Monsoon rainfall. Before the year 2003, the LRF model is used to be a 16 parameter power regression statistical model (Gowariker et al., 1991). However, from the year 1999 onwards, forecasting of the rainfall with such a 16 parameter model is not consistent with the measured rainfall variability. Hence this year (Sen, 2003), IMD used 8 parameter model for forecasting the rainfall. Let us hope that the forecasts from the present model will come true. If not, one has to search and include other precursors/parameters that strongly relate with the rainfall variability. One such parameter that may be included in the LRF is the sunspot activity occurrences. In fact, at least in the long period (>10 years) range, the well-known solar cycle and activity phenomenon is much better correlated with the rainfall variability. The reason in not including the parameter (solar activity phenomenon) in the LRF could be due to conflicting and contradictory results (for example, low or high significance of correlation coefficients) from the correlative studies of the occurrences of the sunspot and the Indian monsoon rainfall variabilities. The main reason for such conflicting and contradictory results is using of annual sunspot occurrences for all the correlative analyses. On the other hand, when we use the seasonal occurrences of the sunspot and the rainfall variabilities, we get statistically significant correlation coefficient from the present study. This is a strong reason that tempt us to suggest that ‘the solar cycle and activity phenomenon may be included as one of the parameters in LRF model’.

By analyzing 130 years data of the sunspot and the Indian monsoon rainfall variabilities, overall conclusions are: (i) the spring and southwest monsoon rainfall variabilities, with a high significance, are positively correlated with the sunspot activity, (ii) the FFT and the wavelet analyses of the annual rainfall variability show the similar periodicities as those found in the sunspot occurrences and, (iii) compared to previous solar cycle there is a long term increasing trend in the sunspot activity by nearly 3.9 ± 1.5 sunspots/year and a long term decreasing trend in the Monsoon rainfall variability by nearly 2.3 ± 1.3 mm/year.

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