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On the Solar Forcing of Rainfall Variations in India During an Extreme Sunspot Cycle

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Abstract

Solar influence on weather phenomena like Indian rainfall variations is well documented in literature. Solar activity shows significant cycle to cycle variability and it is observed to be maximum during the 19th sunspot cycle period (1954-64) when we consider direct sunspot observations during the past 315 years. It will be important and interesting to know what part of rainfall variability in India is associated with solar activity changes when we take in to account other influences such as El Nino. Since solar as signal to noise ratio on weather is expected to be maximum during the extreme "sunspot cycle 19" we have separated the All India rainfall data published by IMD in to seasons and months to study its associations with corresponding sunspot number variations. Solar forcing of rainfall variations in India is observed with weak to moderate statistical significance for the months of May, July, September, November and December in this sunspot cycle. Summer monsoon rainfall in India is found to be almost normal during the entire period of this exceptional solar cycle possibly due to significantly enhanced solar radiative forcing as evident from Solar 10.7cm radio flux variations.

Key words : Solar forcing- All India rainfall-Sunspot activity-19th Solar cycle

1 Introduction

Understanding and predicting rainfall variability in India finds applications in areas like "agriculture, hydrolog" and economic planning. From several studies during the past 140 years we can find that Indian monsoon rainfall is influenced by solar

activity changes¹⁻⁷.

Reliable observations of sunspot number which is an important indicator of solar activity is available since the year 1700. The present time series of sunspot data covers 32 sunspot cycles. The maximum yearly mean sunspot number for a given sunspot cycle is usually referred as amplitude of the

cycle. It is found that the amplitude of the sunspot cycle is maximum during the cycle 19 which spans the period 1954-1964. Solar output in the form of energetic radiation (EUV, Xrays etc.) and energetic particles (solar proton events) is also expected to show extreme values⁸, during this cycle which in turn can influence our weather system also. There are no previous studies which has explicitly focused the associations between solar activity and weather changes in India during the abnormally active sunspot cycle 19.

Previous studies on Sun-weather relations has mainly used rainfall data of India published by IITM, Pune based on 306 rain gauge stations with a coverage of about one station per 10,000 sq km in area. But recently Indian Meteorological Department (IMD) has published area weighted mean rainfall observations in India based on more than 2000 rain gauges through out this country with a homogenous spatial coverage of one station per 3000 sq km approximately based on an earlier work by⁹. The IMD rainfall data is far more accurate than the IITM rainfall data and is used in the present study.

In this paper we have studied the salient features of monthly and seasonal all India rainfall variability during sunspot cycle 19 in association with sunspot number variations. It is found the summer monsoon rainfall in India is almost normal during the entire sunspot cycle. Further year to year changes in monthly All India rainfall variations is found to be influenced by the sunspot cycle during the months of May, July, September, November and December.

2 Details of data used:

(i) All India monthly and seasonal rainfall data (area weighted means) obtained from the IMD website for different months of the years 1954-1964¹⁰.

(ii) Sunspot number (R) is an index of the activity of the entire visible disk of the Sun. It is defined by the relation

$$R = K (10g + s),$$

Here g is the number of sunspot groups and s is the total number of distinct spots observed on the visible solar disk. The scale factor K (usually less than unity) depends on the observing conditions.

International Sunspot Numbers (Ri) is calculated from sunspot observations of more than twenty-five observatories in the world and are comparable with classic Zurich sunspot numbers (Rz). In this paper we have used monthly and yearly pre-revised sunspot numbers available in the NGDC website¹¹.

(iii) The sun emits radio waves with a slowly varying intensity. It originates from solar chromosphere and corona and shows day-to-day, variations according to variable sunspot activity. Solar radio flux at 2800 MHz (10.7 cm wavelength) at Ottawa in Canada and Penticton in British Columbia is used to prepare the index of solar activity called solar 10.7 cm radio flux. This index is highly correlated with sunspot number and is a proxy of solar short wavelength electromagnetic radiations. In this paper we have used yearly mean Ottawa Solar 10.7 cm flux index available in the NGDC website for the years 1954-64¹².

3. Monthly and seasonal rainfall variations in India during the 19th solar cycle in association with sunspot number variations :

In Fig 1 we have plotted All India rainfall observed during the January months of the years 1954-1965. For comparison we have also plotted monthly mean International sunspot numbers for these months in the same figure. In a similar way we have plotted values of All India rainfall observed for February, March etc. up to December during the above years of study in Fig 2 to Fig 12 respectively. The nature of sunspot cycle variability of Indian rainfall for each month is briefly described in Table 1.

Linear correlation coefficient is first developed by Karl Pearson and is also known as Pearson product moment correlation coefficient. It varies between +1 and -1. Correlation coefficient [Correl (X,Y) or r] between two time dependent variables x and y is defined by the equation

$$\text{Correl}(X, Y) = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}$$

Where \bar{x} and \bar{y} are arithmetic means of time series x and y respectively. Students t test can be used to determine the statistical significance of linear correlation coefficients.

Monthly linear correlation coefficients between variations of All India rainfall and sunspot number are estimated using MS Excel software and these values are also given in Table 1. Correlation coefficients equal to or above 0.4 are given in bold letters in this Figure.

In Fig 13 to Fig 16 we have plotted All India rainfall observed during the four seasons separately: Winter (January and February), Pre-monsoon (March –May), Summer monsoon (June-September) and Winter monsoon (October-December) for the years 1954-65 along with yearly mean International sunspot number for the above years. In Fig. 17 we have plotted annual rainfall variations in India for the same period along with sunspot number. The correlation coefficients between the variations of rainfall and sunspot number for these five categories are also estimated and given in Table 2.

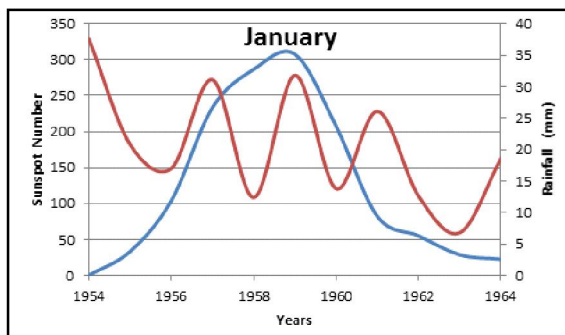


Fig. 1 All India Rainfall (red) and Sunspot number (blue) for January

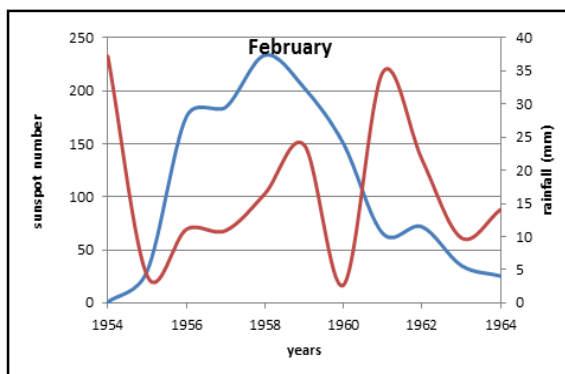


Fig. 2 All India Rainfall (red) and Sunspot number (blue) for February

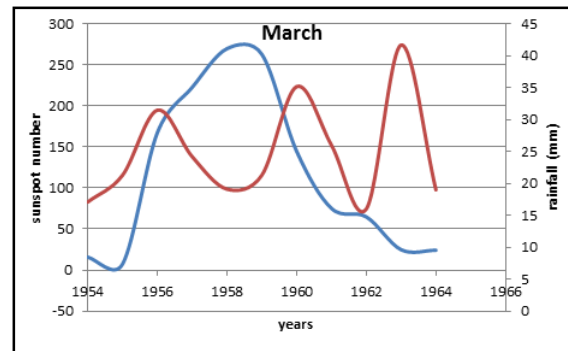


Fig. 3 All India Rainfall (red) and Sunspot number (blue) for March

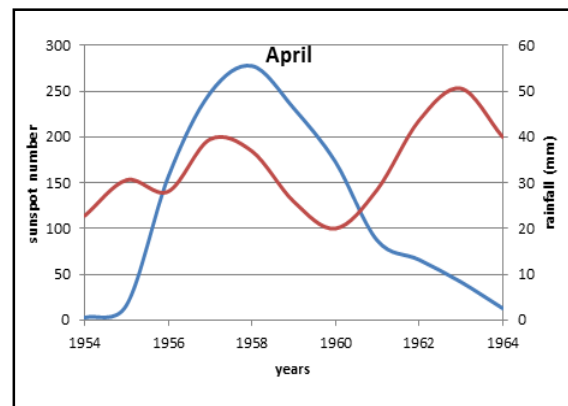


Fig. 4 All India Rainfall (red) and Sunspot number (blue) for April

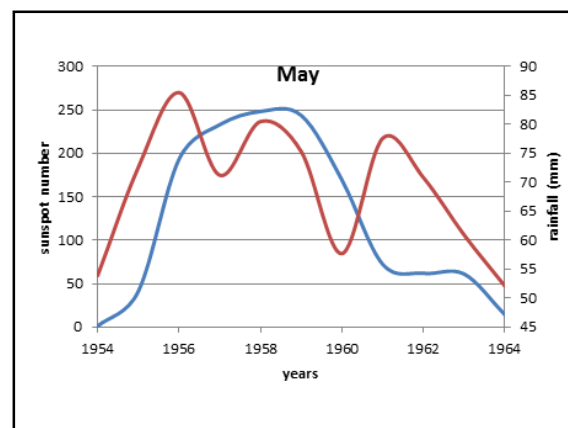


Fig 5 All India Rainfall (red) and Sunspot number (blue) for May

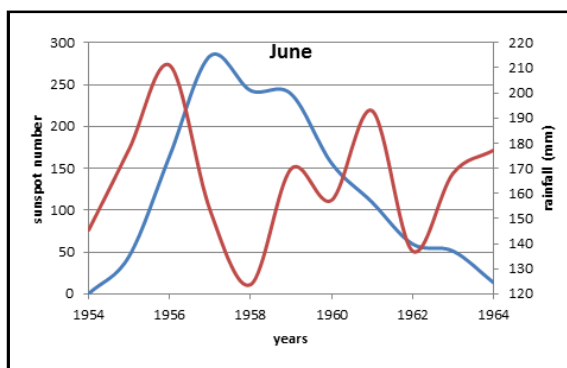


Fig. 6 All India Rainfall (red) and Sunspot number (blue) for June

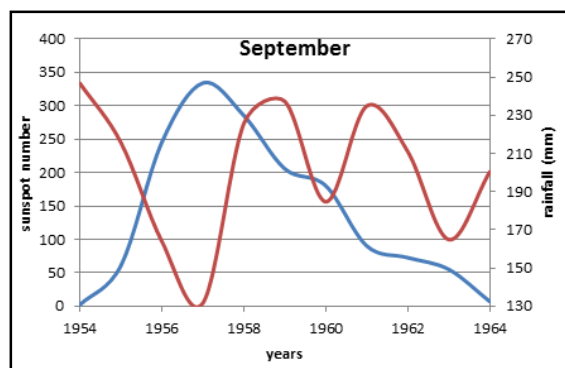


Fig. 9 All India Rainfall (red) and Sunspot number (blue) for September

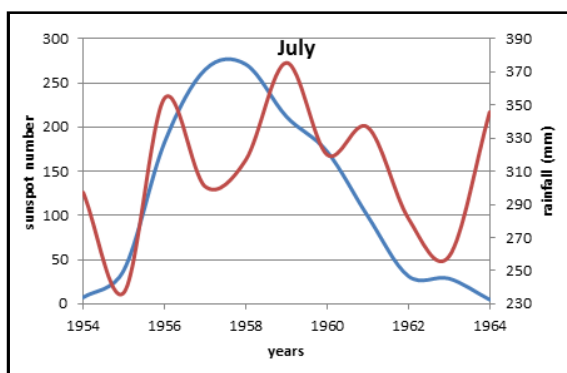


Fig. 7 All India Rainfall (red) and Sunspot number (blue) for July

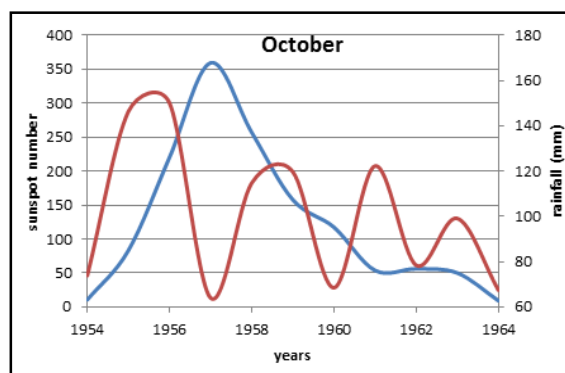


Fig. 10 All India Rainfall (red) and Sunspot number (blue) for October

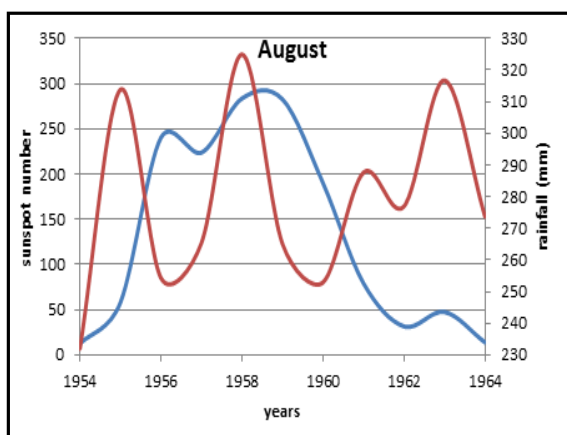


Fig. 8 All India Rainfall (red) and Sunspot number (blue) for August

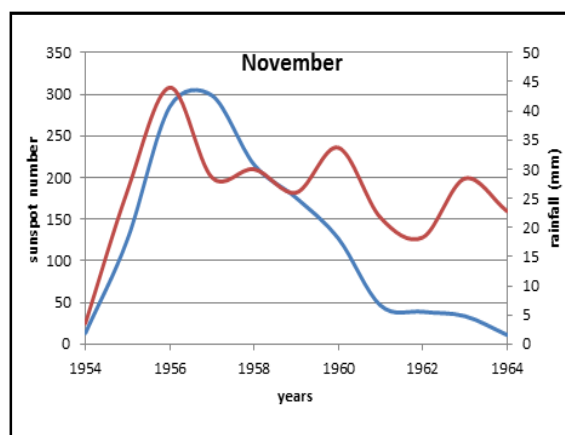


Fig. 11 All India Rainfall (red) and Sunspot number (blue) for November

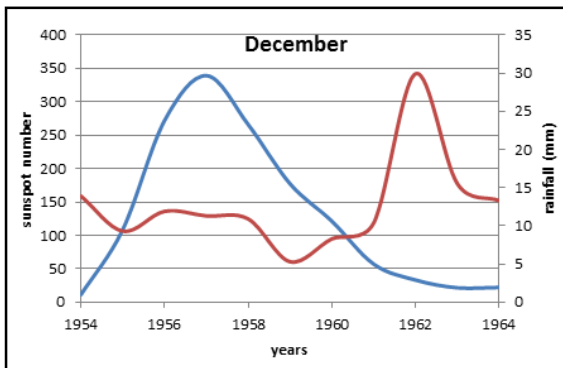


Fig. 12 All India Rainfall (red) and Sunspot number(blue) for December

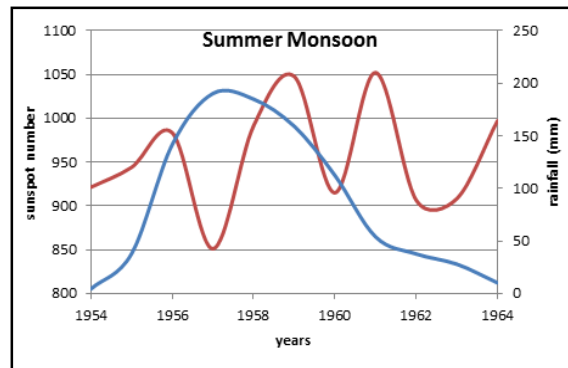


Fig. 15 All India Rainfall (red) and Sunspot number (blue) for the Summer-Monsoon season

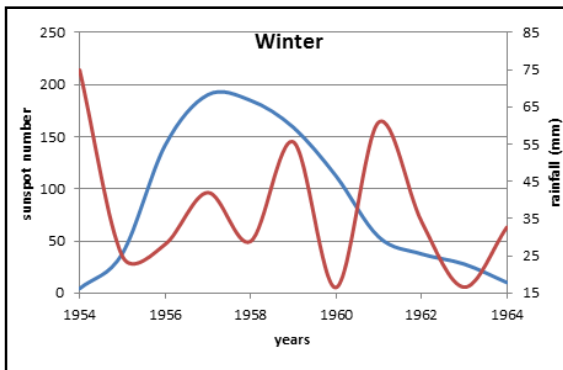


Fig. 13 All India Rainfall (red) and Sunspot number(blue) for the winter season

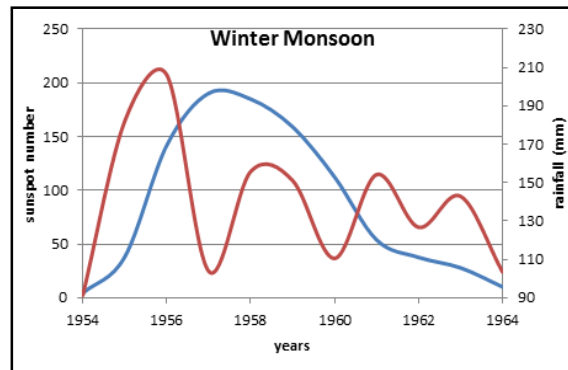


Fig. 16 All India Rainfall (red) and Sunspot number (blue) for the Winter-Monsoon season

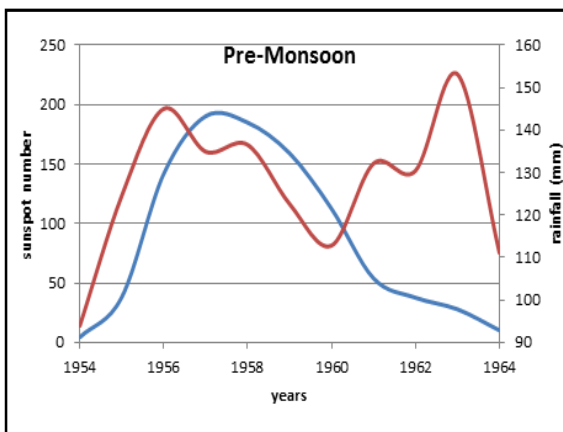


Fig. 14 All India Rainfall (red) and Sunspot number (blue) for the Pre-monsoon season

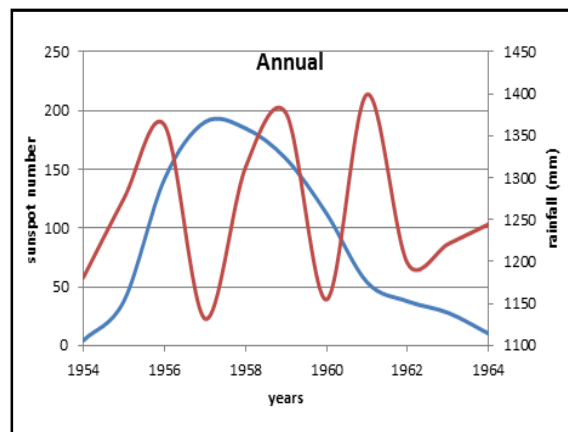


Fig. 17 All India Annual Rainfall (red) and Sunspot number (blue)

Table 1 Observations related to association of All India monthly rainfall with sunspot activity during cycle 19 and estimated correlation coefficients for each month

Month	Remarks about relation of rainfall variations with sunspot cycle if any	Correlation coefficient
January	Fluctuating and noisy	0.1
February	Shows positive correlation during rising phase of the sunspot cycle	-0.231
March	Oscillating and noisy	-0.033
April	Fluctuating in general	-0.136
May	Increasing trend during the rising phase of the sunspot cycle	0.596
June	Shows negative correlation with sunspot number variations	-0.135
July	Follows sunspot activity cycle in general	0.44
August	Increasing trend during the rising phase of the sunspot cycle	-0.01
September	Shows negative correlation with sunspot number variations	-0.49
October	Generally fluctuating and noisy	0.11
November	Remarkable positive correlation with sunspot activity cycle	0.70
December	Shows negative correlation with sunspot cycle	-0.40

Table 2 Observations related to association of All India seasonal and annual rainfall with sunspot activity during cycle 19 and estimated correlation coefficients for each category

Season	Remarks about association with sunspot cycle	Correlation coefficient
JF	Increasing trend during ascending phase of the sunspot cycle	0.119
MAM	Correlated changes with sunspot activity during ascending and maxima phases of the sunspot cycle	0.356
JJAS	Fluctuating and no definite phase relation with the Sunspot cycle	0.046
OND	Oscillating and no definite trends	0.244
Annual	Fluctuating and no correlation with sunspot activity changes	0.17

4 Discussion

India as a country has spatial differences in geographical and climatological features which will affect the sunspot cycle effects on All India rainfall variations. Some studies actually found spatial variations on the solar activity effects on temporal changes in monsoon rainfall in India¹³. These aspects will reflect on the correlation coefficients given in Tables 1 and 2. Inter seasonal variations can explain poor seasonal All India rainfall correlations with sunspot activity (see Table 2). For example during

the summer monsoon season (June to September) the effect of positive correlation found in July is opposed by nearly equal negative correlation found during "September. (See Table 1)" In a similar manner during the winter monsoon season (October to December) the moderate positive correlation during November is opposed by weak negative correlation during December. The p values in a test are measures of the confidence interval associated with significance of linear correlation coefficients. The p values show 95 % significance for May and 98% for November between monthly all India rainfall-sunspot activity

correlations in the 19th cycle in a two tail test. The significance levels are however relatively low being 82 % for July and 78 % for December.

As explained above we could find statistically meaningful positive correlations between rainfall variations in India and the sunspot cycle for the months of May, July and November during the 19th solar cycle. May is the month maximum pre-monsoon thunderstorm activity in India. During July summer monsoon conditions is active throughout the country. North-east monsoon conditions are most active during the month of November for which we could find highest correlation with the sunspot cycle. During the months of retreat of summer monsoon (September) and winter monsoon (December) we could observed statistically significant negative correlations with sunspot activity variations. Both positive and negative correlations are quite common in Sun-weather relations. Some authors has explained the negative correlation between monsoon rainfall in India and sunspot activity changes due to cosmic ray intensity changes¹⁴. which is subjected to strong criticism¹⁵. Even during the most active sunspot cycle period (1954-64) only for few months we could find correlated changes between rainfall in India and sunspot number variations. This is because All India rainfall is influenced by several non-solar factors of terrestrial origin such as sea surface temperature, El Nino ,global warming, aerosol forcing etc.¹⁶⁻¹⁷

The long period averages of summer monsoon rainfall in India (normal value) as determined from area weighted mean observations published by IMD for the years 1901-2016 is found to be 875.5 mm¹⁸. In comparison with this we can find that almost throughout the extremely active sunspot cycle 19, the summer monsoon rainfall in India is comparable or slightly above this normal value. 70% of annual rainfall in India happens during the summer monsoon season. Normal monsoon in India ensures good agricultural production and favorable economic conditions.

Several authors suggested that solar radiative forcing (10.7cm solar radio flux is its proxy) is important for understanding sunspot cycle effects on Indian monsoon rainfall⁶⁻⁷. Solar 10.7cm radio flux observed near earth is found to be significantly high during

sunspot cycle 19 as evident from a plot of the same in Fig 18. The observation of normal summer monsoon rainfall in India almost throughout the sunspot cycle is perhaps associated with significant enhancements in solar 10.7cm radio flux obseved during this sunspot cycle.

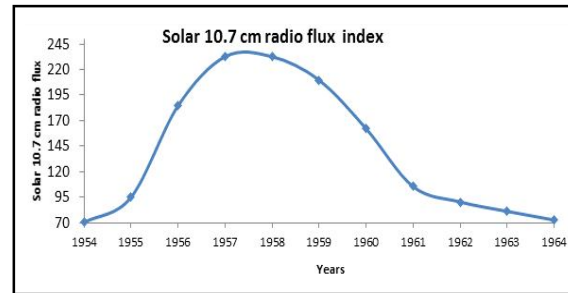


Fig. 18. Variations of yearly mean Solar 10.7 cm Ottawa radio flux index during the sunspot cycle 19.

5 Conclusions

From a study of All India monthly and seasonal rainfall variations in association with sunspot number variations during the extreme sunspot cycle 19 (1954-64) we could find :-

(i) Positive correlation with weak to moderate statistical significance between variations of above two parameters during the months May (pre-monsoon), July (summer monsoon) and November (winter monsoon). Negative correlation is found for the same during the months September and December.

(ii) Normal summer monsoon rainfall is observed in India almost through out the sunspot cycle 19 which is possibly related to significantly enhanced solar radiative forcing on Indian weather systems during this exceptional solar cycle. The result that enhanced solar activity as in 19th sunspot cycle period is associated with normal summer monsoon will have predictive value if it is verified for other sunspot cycles also. This will be addressed in a future publication. (Ambily *et al.*, 2017, manuscript under preparation).

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