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The Influence of Solar Activity on the Rainfall over India: Cycle-to-Cycle Variations

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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 rainfall over India. For the period of different solar cycles, we compute the correlation coefficients and significance of correlation coefficients for the seasonal months of Jan–Feb (JF), Mar–May (MAM), June–Sept (JJAS) and Oct–Dec (OND) and, *annual mean* data. We find that: (i) with a moderate-to-high significance, Indian rainfall is correlated with the sunspot activity and, (ii) there is an overall trend that during the period of low sunspot activity, occurrence of rainfall is high compared to the period of high sunspot activity.

We speculate in this study a possible physical connection between the occurrence of the rainfall and the sunspot activities and, the flux of galactic cosmic rays. Some of the negative correlations between the occurrences of the sunspot and rainfall activities obtained for different solar cycle periods are interpreted as effects of aerosols on the rain forming clouds due to either intermittent volcanic eruptions or due to intrusion of interstellar dust particles in the Earth's atmosphere.

Key words. Solar activity—Indian rainfall—galactic cosmic rays—volcanic or interstellar dust.

1. Introduction

Being predominantly an agricultural country, the Indian economy depends mainly on rainfall. For the last few years, drought has hit the world's 12th largest economy. The dominant contribution ($\sim$ 25% of the gross domestic product) towards the country's economy is agriculture which depends mainly upon the monsoon rainfall. For the last successive years, the Indian subcontinent witnessed the miserable failure of southwest monsoon that led to severe droughts. Causes for the abnormal activities of the rainfall over India such as occurrence 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 and other unknown causes. Another cause which is clearly discernible in most of the recent findings is due to solar radiative forcing over the global climate and the environment of the Earth. Recent studies (Hiremath and Mandi 2004 and references therein) indicate that the solar cycle and related activity phenomena have a good correlation with the Earth's global climate and temperature. In the previous study (Hiremath and Mandi 2004), we investigated the long term (> 20 yrs) influence of the solar activity on the Indian monsoon rainfall. In the present study we investigate the effect of the solar activity for a short term (~ 11 yrs) scale and study the cycle-to-cycle variations of the influence of the solar activity on the rainfall over India.

2. Data and analysis

We consider 130 years (1871–2000) data of the sunspot numbers and the rainfall occurrence activity (Parthasarathy *et al.* 1993; *http://www.tropmet.res.in*) over India. The sunspot number data is considered from the National Geophysical Data Center, Boulder, Colorado, USA (*http://www.ngdc.noaa.gov/STP/SOLAR/SSN/ssn.html*). Parthasarathy *et al.* (1993) have compiled a homogeneous set of rainfall data from the 14 meteorological subdivisions covering the northwestern and central parts of India (about 55% of the total area of the country). 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.

The different nomenclatures for the seasonal rainfall occurrences are given 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 data set, we denote as MAM. In the 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. For a particular year, we compute the average of all the 12 months rainfall data and call it as *annual mean* of the rainfall data. For similar combined months (JF, MAM, JJAS and OND), we collect the sunspot data. For each year, by using 12 months data, we compute *annual mean* of the sunspots. In Table 1, we present the the Spearman Rank-Order correlation coefficients (and significances) computed between the occurrences of sunspot and rainfall activities from the raw data. This method (Press *et al.* 1992) of finding the correlation between two variabilities is more robust than the usual method (*i.e.,* by linear correlation). The first column represents the solar cycle period, the second column, the length of the solar cycle, the third column, total area of the rainfall occurrence variability and, the fourth column, the area of the solar cycle. Following Hiremath and Mandi (2004), the length of the solar cycle, area of the solar cycle and area of the rainfall occurrence variability are computed. In the fifth to last columns, the results for the combined seasonal months of JF (winter), MAM (summer), JJAS (southwest), OND (southeast) and the annual mean correlation coefficients have been presented. The significance of correlation coefficients are given in brackets just below the values of correlation coefficients.

The absolute values of the correlation coefficients (seasonal and annual) presented in Table 1 are plotted with respect to the annual area of the solar cycle in the first plot of the Fig. 1. In the rest of the four plots of Fig. 1, we illustrate separately each of the seasonal months' correlation coefficients with the seasonal sunspot cycle area. In the last plot of Fig. 1, correlation coefficients for the annual with respect to the annual solar cycle areas are presented. By taking significance of correlation coefficients as errors in the obtained correlation coefficients, we subject both the seasonal correlation coefficients and solar cycle area data set to the linear least square fit of the form

Table 1. Cycle-to-cycle variation of correlation coefficients for the seasonal months (JF, MAM, JJAS and OND) and annual raw data respectively. The values in brackets are significance of the correlation coefficients. Length of the solar cycle is computed from min-min years.

Year	Length	Rainfall area	Cycle area	JF	MAM	JJAS	OND	Annual
1878–1889	12	11008.5	4633.6	0.09 (0.22)	−0.22 (0.50)	0.13 (0.32)	−0.11 (0.27)	0.08 (0.12)
1890–1901	12	10332.0	5541.0	0.25 (0.56)	−0.10 (0.24)	0.50 (0.91)	0.70 (0.99)	0.55 (0.92)
1902–1913	12	9572.9	4469.8	0.22 (0.51)	0.36 (0.75)	−0.12 (0.29)	−0.41 (0.82)	−0.04 (0.10)
1914–1923	10	7096.8	4459.0	0.16 (0.35)	0.50 (0.86)	0.55 (0.90)	0.55 (0.90)	0.21 (0.44)
1924–1933	10	7355.0	4103.6	0.38 (0.72)	−0.36 (0.69)	−0.20 (0.42)	−0.35 (0.67)	−0.41 (0.76)
1934–1944	11	8941.0	6698.6	−0.16 (0.37)	0.17 (0.39)	0.11 (0.26)	0.38 (0.75)	−0.34 (0.69)
1945–1954	10	7379.4	7514.4	−0.02 (0.04)	0.26 (0.53)	−0.30 (0.60)	0.52 (0.87)	0.22 (0.47)
1955–1964	10	8009.2	9547.0	0.39 (0.78)	0.38 (0.72)	−0.36 (0.69)	0.29 (0.56)	0.07 (0.15)
1965–1976	12	9942.6	8494.7	0.14 (0.34)	0.32 (0.68)	−0.04 (0.10)	−0.27 (0.61)	−0.05 (0.12)
1977–1986	10	7137.7	8306.3	0.03 (0.07)	−0.03 (0.07)	0.16 (0.35)	−0.13 (0.27)	0.30 (0.60)
1987–1996	10	7149.9	7802.0	−0.73 (0.99)	0.25 (0.50)	0.36 (0.69)	−0.46 (0.81)	−0.01 (0.01)

$R = a + bS$ (R is the correlation coefficient, S is the area of the solar activity, a and b are usual constants). The results obtained from such a linear relation with goodness of fit is inserted at the top of each plot. The red continuous line over plotted in each of the plot is computed from the least square fit.

One can argue that the correlations (presented in Table 1) within a cycle are rarely significant to draw any conclusion. The following are the two most likely reasons for the low significance of correlation coefficients (CC). The first problem is estimation of the significance of correlation coefficients (CC). The best and correct way is to have measured uncertainties in the rainfall data and compute the CC and their significances. Unfortunately we don't have any measured uncertainties in the rainfall data considered in this study. Thus we have considered $(N)^{1/2}$ (where N is the number data points in each variable) as measured uncertainty in each rainfall data. The second problem is the low accuracy of the rainfall data that are measured from the rain gauges.

Though the uncertainties in the derived coefficients are large, we can draw the following conclusions: for a particular solar cycle period, there appears to be an

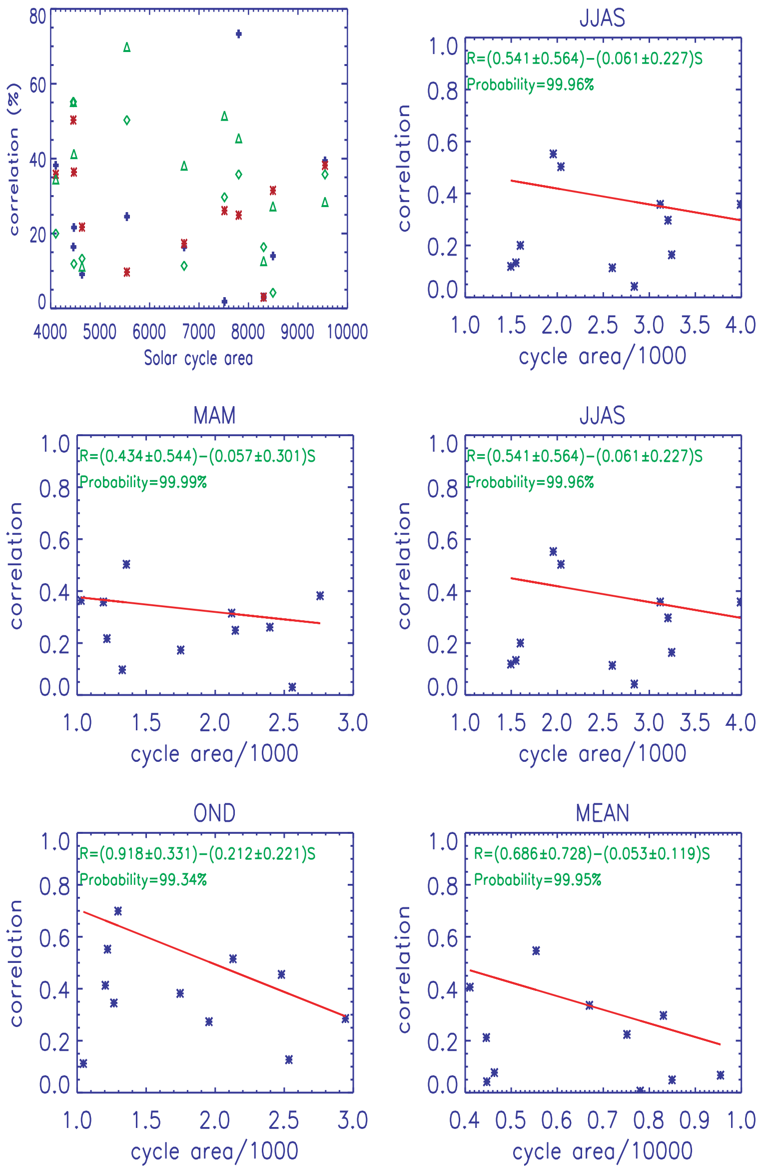

Figure 1. Different cycle-to-cycle variations of the correlation coefficients for the seasonal months are plotted against the annual area of the solar cycle. Different symbols in the first plot are: JF as +, MAM as ∗, JIAS as ⋄ and OND as △. The rest of the plots represent the same as in the first plot, except that data are presented separately (for different seasonal months) with a line (in red colour) that is obtained from the linear least square fit is also over plotted.

overall trend that irrespective of signs of the correlation coefficients, the monsoon rainfall variability is strongly correlated during the weak sunspot activity and weakly correlated during the strong sunspot activity. That means during the 11-year solar cycle, *a weak sunspot activity leads to a strong Indian rainfall variability and vice versa*.

3. Conclusions and discussion

From the correlative analysis of 130 years data of the sunspot and the Indian monsoon rainfall activities, conclusions of the present study are:

- with a moderate-to-high significance sunspot activity is correlated with the Indian rainfall activity,
- irrespective of signs of the correlation coefficients, for a particular period of a solar cycle, there appears to be an overall trend that rainfall variability is high during the low solar activity than the high solar activity.

As for the low-to-moderate correlations, as we discussed in the previous study (Hiremath and Mandi 2004), there is a *causal relationship* between the sunspot activity, galactic cosmic rays (GCR) and the rainfall in the following way. The GCR activity is the source of ions in the Earth's atmosphere. We know that the condensation of water vapour into water drops is mediated by the ions in the atmosphere. Thus any change in the GCR activity correspondingly affects the rainfall variability. 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 suppressing the rainfall variability (Parker 1999). That means during high sunspot activity we should get a small correlation coefficient (considered as absolute value) between the occurrence of sunspot and the rainfall variabilities. That is what we are finding in most of the plots.

It is expected from the previous study (Hiremath and Mandi 2004) that for all the seasonal and annual rainfall data one should get positive correlation. Whereas negative correlations in some of the cycle periods could be due to the changing spatial and the temporal occurrence pattern of the aerosol particles either due to intermittent volcanic eruptions (Robock 2000) or due to intrusion of interstellar dust particles in the atmosphere. The recent study (Vinoj *et al.* 2004) shows the rain-deficit of the summer monsoon due to large aerosol optical depths. In fact there is a constant accretion ($\sim (4.0 \pm 2.0)10^6$ kg/year) of cosmic dust due to extra terrestrial origin on the Earth's atmosphere (Lone & Brownlee 1995; Yada *et al.* 2000; Lal & Jull 2002). In the present context, it is very difficult to judge as to which of the aerosol particles influences the Indian rainfall.

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