

Connection between Rainfall and Solar Activity Features during Solar Cycle 20 to 24

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This study examines the statistical relationship between all-India homogenous rainfall (RF) and different Solar Activity Features (SAF) - Sunspot Number (SN), Solar Active Prominence (SAP) and Solar Flare (SF) throughout five consecutive solar cycles (20 to 24) from 1964 to 2019. For all yearly and seasonal periods RF has a significant correlation coefficient with SAF (SN, SAP, SF). It shows a positive trend of RF from solar cycle 20 to 24. In various solar cycle phases, the RF exhibits distinct variability. We found two prominent periods of 2.5 year and 3.5 year for RF when studied the annual variation of RF over the period of 55 years (cycle 20-24) and other periods were ranging from 2 to 10 year. According to the RF normal probability distribution studied over 55 years, we found that 700-750 mm RF is most likely to occur. Our investigation concludes that RF variability is influenced by SAF incidence.

Keywords: Rainfall; Sunspot numbers; Solar flare; Solar active prominence

1 Introduction

The Sun directly controls and determines how often the climate changes. The Earth's changing climate and weather patterns are directly caused by and governed by the Sun. The Sun is responsible for creating the weather because it heats the globe continuously, but not necessarily in the same places at the same time. These variations in warmth are what lead to the weather. Water evaporates when heated by the Sun, forming clouds that eventually turn into rain. Therefore, natural phenomena like rainfall, climate change, etc., cannot occur without the radiation occurring from Sun. On the surface of Earth, clouds are primary cause of rainfall fluctuation. The relationship between temperature and temperature variation is influenced by solar events and Earth's weather cycles¹⁻³. Statistical studies done by various authors⁴⁻²¹ in this field suggested that through a chain combining clouds, SAF, and galactic cosmic rays (GCR) and solar variability may be connected to climate variability. The background source of energetic particles that continuously pelt Earth is the galactic cosmic rays (GCR), which are a slowly fluctuating, extremely energetic source and rainfall on Earth is significantly influenced by these rays⁴⁻⁷. More cosmic rays can enter the Earth's atmosphere during

solar minimum and maunder minimum because of the low solar activity and weak interplanetary magnetic field. As a result, there is a chance of precipitation as the cloud cover increases. High rainfall arises when drop in galactic cosmic rays is encountered and increment in solar activity²²⁻²³. (Hiramath & Mandi)²⁴ provide evidence of the impact of solar activity forcing on the climate and environment of the world. Indian rainfall activity for all seasons and yearly data exhibits a substantial link with sunspot levels. According to statistics from Bhattacharyya *et al.*²⁵, the mean rainfall becomes high with the increment in solar activity features. In a statistical analysis of solar activity characteristics and the homogenous rainfall throughout the India from 1963 to 2006, Bankoti *et al.*²⁶ found a strong association between these two parameters. To analyze the distinctive fluctuations and look for any potential correlations, average sunspot data and rainfall data from 1820 to 2005 were used. The investigation shows a significant correlation between the annual Indian rainfall pattern and the average number of sunspots²⁷ (Tripathi *et al.*). Gautam *et al.*²⁸ investigated the possible relationship between solar activity and monthly rainfall in Pokhara and Kathmandu cities in Nepal from the year 1968 to 2023. (Thomas *et al.*)²⁹ found the relationship between solar activity and extreme rainfall events in Kerala, India. Kerala

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receives minimum and maximum rainfall during the winter and monsoon seasons, respectively. Sunspot number, F10.7 Index, and cosmic ray intensity are the solar indices considered and their variations with rainfall were studied over a period of 57 years (1965-2021), i.e., starting from Solar Cycle 20. For each solar cycle, correlative studies are performed and correlation coefficients are calculated.

In 2006, Hiremath³⁰ presented an FFT analysis of the homogeneous rainfall all over the India with the sunspot numbers. It became clear that RF showed periodicity much like SN. He found the periodicity of 22, 16, and 2.7 years. Consequently, it was shown that SAF had a big impact on rainfall activity. Selvaraj *et al.*³¹, did a cycle-to-cycle study and found “rainfall throughout the India reaches at its maximum when sunspot counts reach at their minimum and vice versa”.

In this paper we have studied the RF with SAF (SN, SF and SAP) using very large data to come up with better statistical results. We have used various solar cycles from cycle 19 to 24 and are investigated for their rising, maximum, and decaying phases. Different statistical tools are employed for the investigation like FFT, regression analysis and probability distribution function etc. Section 2 contains the data set. In section 3, results are described and these are discussed. Conclusion is presented in section 4.

2 Data Set

The current analysis employed RF and SAF (sunspot number (SN), solar flare (SF), and solar active prominence (SAP) data over the 55-year period (1964-2019), which contained five consecutive solar cycles 20 to 24. The RF data is obtained from (<http://www.tropmet.res.in>) Indian Meteorological Data Center. The following websites are used to acquire the data of sunspot numbers (SN), solar flares (SF), and solar active prominences (SAP):

<http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-indices/sunspot-numbers/>

<http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-ares/h-alpha/>

<http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solarfeatures/prominences/filaments/>

According to various seasonal months, the RF and SAF data were separated into four portions. Winter data for January and February is designated as JF, whereas spring months (March, April, and May) are

designated as MAM. The southwest monsoon months June, July, August and September are identified as JJAS and October, November and December, the northeast monsoon months are depicted as OND. Since, the all India rainfall data is zig-zag so all the data of rainfall and solar activity features (SN, SF and SAP) is normalized by mean and standard deviation. Here, we've used the coefficient of correlation formula to compute the correlation between the RF and various SAF for both yearly and seasonal months:

$$\text{Coeff of Correlation } r = \frac{n(\sum r.s) - (\sum r)(\sum s)}{\sqrt{[n\sum r^2 - (\sum r)^2][n\sum s^2 - (\sum s)^2]}} \quad \dots (1)$$

Where, r= Rainfall data, s= Solar activity features and n = number of data points.

3 Results and Discussion

In this section we have discussed the results of different analyses done between rainfall and solar activity features.

3.1 Statistical analysis of rainfall with different solar activity features

Annual variations in (a) rainfall (RF), (b) sunspot numbers (SN), (c) solar active prominence (SAP), and (d) solar flares (SF) are depicted in Fig. 1. For both yearly and seasonal months, scattered graphs between RF and various SAF are shown in Fig. 2-6. Annual scattered plots of RF with (a) SN, (b) SF, and (c) SAP are shown in Fig. 2. The applied linear fit curves, linear fit equations and correlation coefficients r and their significance at 0.05 significance level (95% confidence level) are written within the accompanying figure. The scatter plots between the RF and SAF seasonal months are shown in Fig. 3-5. Plots for the seasonal months JF, MAM, JJAS, and OND are shown in Fig. 3-6 respectively. According to the relevant figures, the correlation coefficient r and their significance at 0.05 significance level (95% confidence level) are displayed in corresponding figure with linear fit line and the fitting equation together.

Yearly correlation coefficients between RF and SAF (SN, SF & SAP) are -0.069, 0.044, and 0.022 respectively and for seasonal months JF, correlation coefficient between RF and SAF (SN, SF & SAP) are 0.027, 0.014 and 0.037. The summer months (MAM) have correlation coefficient value of 0.10, 0.11 and 0.12 between RF and SAF (SN, SF & SAP). For monsoon seasonal months JJAS, correlation coefficient between RF and SAF are -0.003, -0.02 and

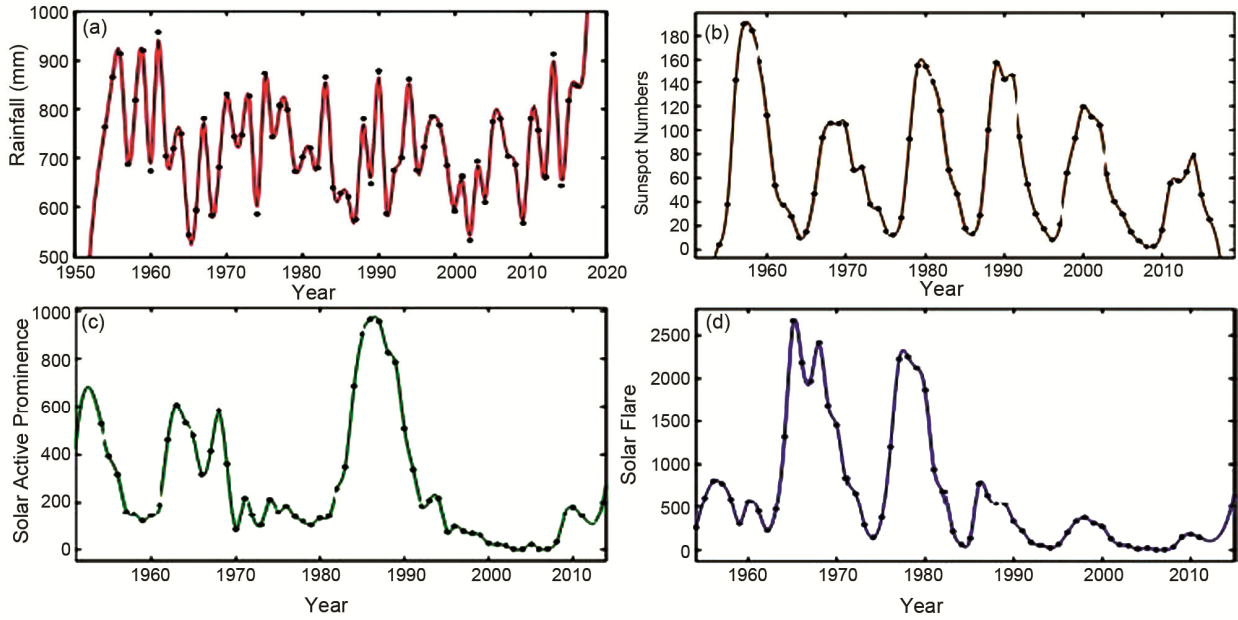


Fig. 1 — Variation of Rainfall (RF) and Different Solar activity features (SAF) SN, SF&SAP from solar cycle 19 to 24

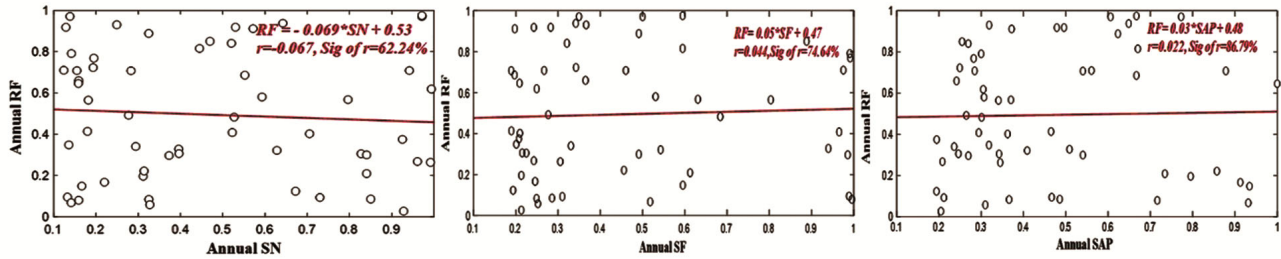


Fig. 2 — Scatter plot of RF (a) Sunspot Number (SN) (b) Solar Flare (SF) (c) Solar Active Prominence (SAP) for annual period

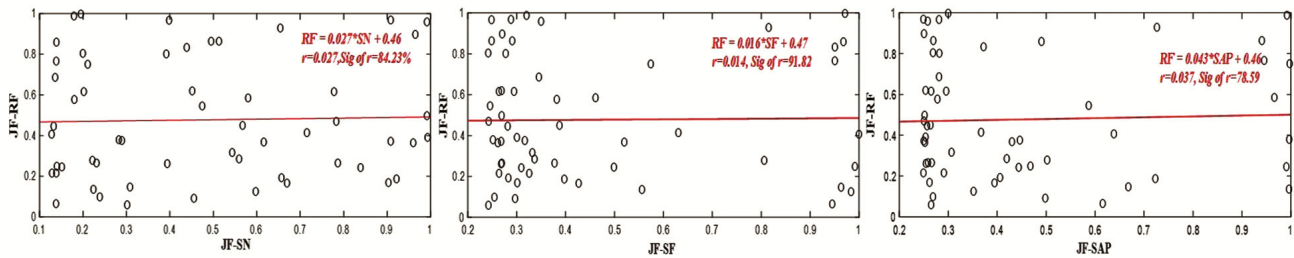


Fig. 3 — Scatter plot of RF (a) Sunspot Number (SN) (b) Solar Flare (SF) (c) Solar Active Prominence (SAP) for winter months JF

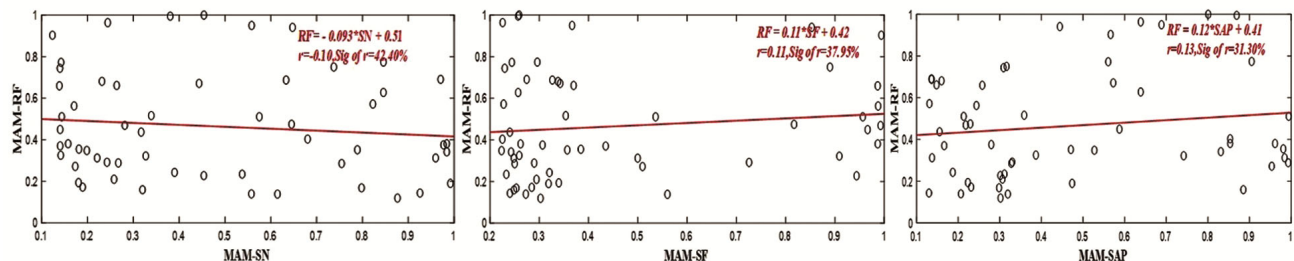


Fig. 4 — Scatter plot of RF (a) Sunspot Number (SN) (b) Solar Flare (SF) (c) Solar Active Prominence (SAP) for summer months MAM

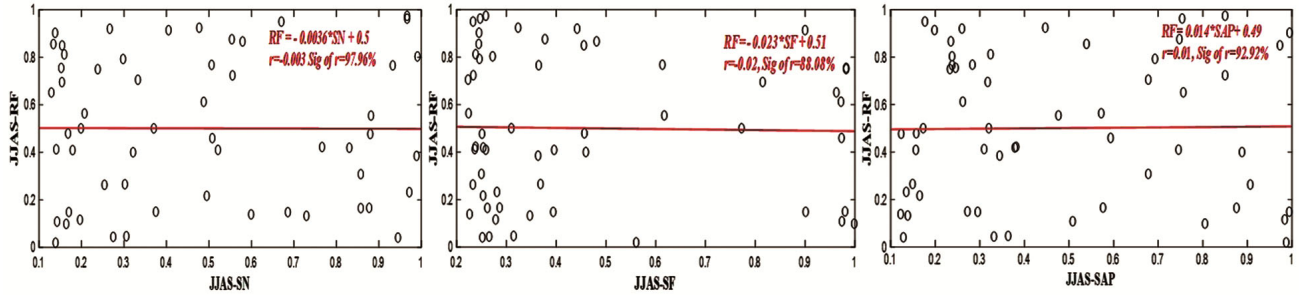


Fig. 5 — Scatter plot of RF (a) Sunspot Number (SN) (b) Solar Flare (SF) (c) Solar Active Prominence (SAP) for monsoon months JJAS

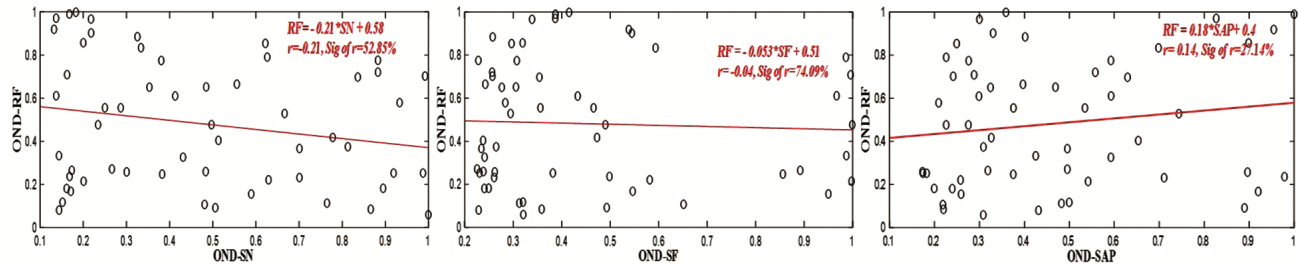


Fig. 6 — Scatter plot of RF (a) Sunspot Number (SN) (b) Solar Flare (SF) (c) Solar Active Prominence (SAP) for months OND

Table 1 — Coefficient of correlations for RF with different solar activity features (SN SF and SAP) and their linear fit equation for annual and seasonal months (JF MAM JJAS OND).

	RF	SN	SF	SAP
Annual	r	-0.06	0.044	0.0022
	Sig of r	62.24%	74.64%	86.79%
	Fitting Equation	RF=-0.06(SN)+0.53	RF=0.05SF+0.47	RF=0.03(SAP)+0.48
JF	r	0.027	0.014	0.037
	Sig of r	84.23%	91.82%	78.59%
	Fitting Equation	RF=0.027(SN)+0.46	RF=0.016(SF)+0.47	RF=0.04(SAP)+0.46
MAM	R	-0.10	0.11	0.13
	Sig of r	42.40%	37.95%	31.30%
	Fitting Equation	RF=-0.093(SN)+0.51	RF=0.11(SF)+0.42	RF=0.12(SAP)+0.41
JJAS	r	-0.003	-0.02	0.014
	Sig of r	97.96%	88.08%	92.92%
	Fitting Equation	RF=-0.0036(SN)+0.5	RF=-0.023(SF)+0.51	RF=-0.014(SAP)+0.49
OND	r	-0.21	-0.053	0.14
	Sig of r	52.85%	74.09%	27.14%
	Fitting Equation	RF=-0.21(SN)+0.58	RF=-0.053(SF)+0.51	RF=0.18(SAP)+0.9

0.01 respectively. The correlation coefficients between RF and SAF (SN, SF & SAP) for seasonal months OND are -0.21, -0.04 and 0.14 respectively. The significance of correlation at 95% confidence level (0.05 significance level) have been calculated and the detailed list of correlation between these parameters, significance of correlation coefficient and linear fit equations are tabulated in Table 1.

3.2 Variation of Rainfall with Sunspots during different Cycle

With a two-point moving average trend line, Fig. 7 depicts the monthly variance in RF over solar cycle 20 to 24 from 1964 to 2019. The distribution of RF in five successive solar cycles (Solar cycles 20 to 24) is

shown in Fig. 8, where a linear trend line illustrating a positive trend can be seen.

The monthly changes in RF throughout the 53-year period under consideration showed that RF is at its highest during the monsoon months (JJAS) and at its lowest at the winter's tail end (January, February), as well as during the summer (MAM). Throughout the year, the two-point moving average line depicts the RF's parabolic tendency. The initial rise reaches its maximum before decreasing. Fig. 8 indicates the rainfall variability from solar cycle 20 to 24. It indicates that solar cycle 24 displayed maximum rainfall than other cycles. There is a positive trend of rainfall in India from solar cycle

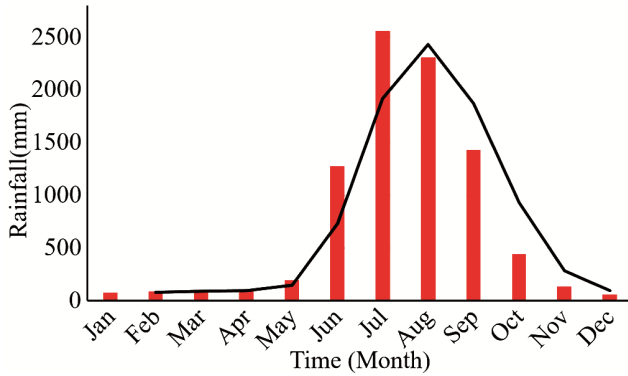


Fig. 7 — Monthly Variation in RF from 1964 to 2019

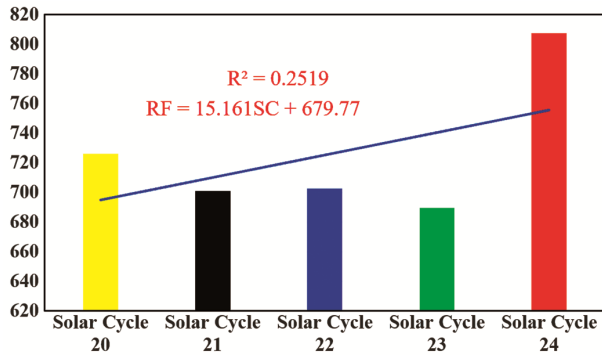


Fig. 8 — Variation in RF from Solar Cycle19 to Solar Cycle 24

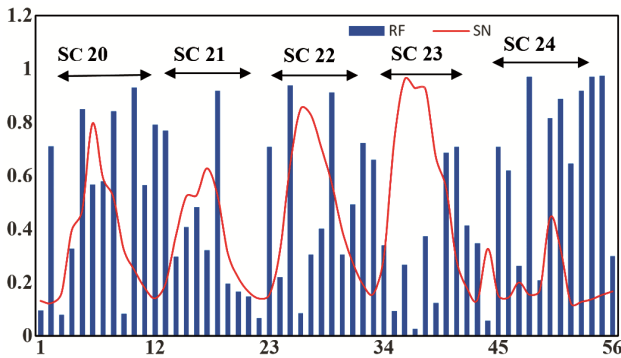


Fig. 9 — Variability in RF with SN from cycle 19 to cycle 24(1954 to 2016)

20 to 24. Its R-square value and trend equation is written in the figure.

The RF variability with SN from 1954 to 2019 is investigated in Fig. 9. The colors blue bar denotes RF and red line plot shows SN respectively. Fig. 9 demonstrates that RF lags behind SN during the period of solar maximum of solar cycles 20 to 24. *i.e.*, when sunspots are at their maximum, RF is at its minimum. Its means that RF during solar maximum out of phase with SN. While during the rising phase of solar cycle RF in phase with SN and declining

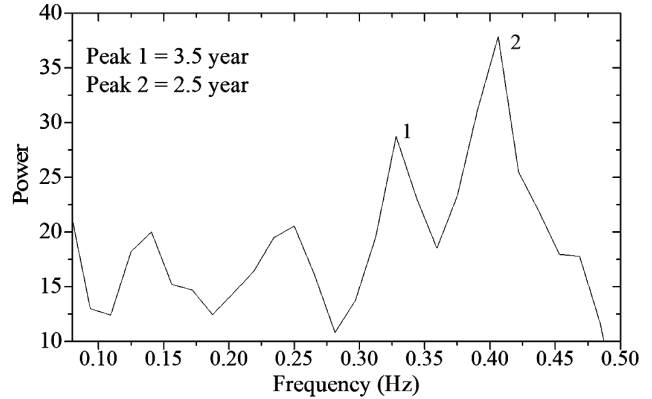


Fig. 10 — Power and frequency spectrum of RF by FFT analysis during 1964 -2019

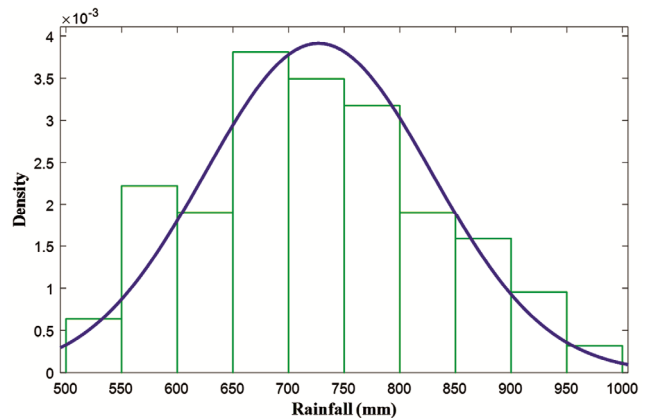


Fig. 11 — Probability density of Rainfall during 1954-2016

phases of solar cycles 20 to 24 exhibit the RF out in phase with SN. According to the results, RF exhibited various levels of variability during the solar cycle.

3.3 Analysis of Variability in Rainfall by Fast Fourier transform (FFT) and probability density of Rainfall

The Sun shows periodic phenomena like sunspots which represent an 11-year solar cycle. Occurrences of RF frequently vary year to year. The periodic nature of RF is studied by applying Fast Fourier transform (FFT) on original data of RF and obtained a power-frequency spectrum of RF (Fig. 10). This spectrum shows different periodicities ranging from 2 year to 10-year (Since frequency ranges from 0.10 to 0.50 Hz and time period is reciprocal of frequency). Most prominent peaks are peak 1(3.5 year) and peak 2 (2.5 year). It means the trend of RF repeats itself in every 2.5and 3.5years. Hence, RF also shows periodic nature like SN.

The most probable RF between 1964 and 2019 was identified using the normal probability distribution of RF illustrated in Fig. 11. The RF mean for 55 years is

726.91mm. The most likely RF in India between 1964 and 2019 is 700 - 750 mm, according to the normal probability distribution of RF for 55-year data.

4 Conclusion

This study represents that RF is influenced by solar activity features. RF and SAFs have a significant correlation coefficient. Because of this, the GCRs' ability to reach the Earth is increased when SAF levels decline and aerosol promotes cloud formation. As a result, Earth's atmosphere experiences more RF incidence. During the monsoon season, there is a significant increase in the rate of variation in rainfall. In the monsoon season, there is a low sun intensity and considerable humidity. During these months, India's atmospheric pressure rises as a result of an increment in the rate of evaporation and aerosol generation. Thus, SAF dropped during monsoon season when RF activity was higher. During the summer, RF drops in India. Summer (MAM) months see an enormous rise in temperature because to SAF's increased sun intensity, although dry days reduce humidity and evaporation, so that there were fewer aerosol forms and less clouds throughout the summer. Due to high intensity in the summer, RF and SAF have a positive association. According to the findings of statistical analysis SAF has a significant effect on RF.

Therefore, variations in rainfall and climate change in the Earth's atmosphere are significantly influenced by solar activity features. In order to comprehend the relationship between the occurrence of RF activity in the Earth's atmosphere and various SAF of the solar atmosphere, this investigation has significant role. SAF affects both seasonal and yearly variations in the homogenous RF over the whole country of India. The Sun controls RF variability. The transmission of energy to the Earth's atmosphere is caused by several SAF of the solar atmosphere and Exhibits variation in atmospheric activities such as temperature fluctuation, RF, and climate change. This study showed that SAF affected the frequency of RF activity. Additionally, it displays various modifications throughout a particular solar cycle phase. It has cyclic behavior.

This statistical investigation came to the conclusion that RF is affected by SAFs and explains rainfall variability during different solar cycles. It also explains the periodic nature of RF like SN. The variations in solar phenomena were documented in Earth atmospheric phenomena like rainfall, climate change, etc. This shows that Earth atmospheric phenomena are reliant on solar atmospheric phenomena.

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